Hydrologic Data and Draft Recommendations Related to the Review of 100-Year Physical Availability Depth Criteria for Demonstrating Adequate Water Supplies
(Study in support of the requirements of SB 1575)

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Public Comment Draft Report

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Table of Contents

Figures

Tables

Appendices

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Purpose

The purpose of this report is to provide general hydrogeologic information on the aquifer systems of rural Arizona that are located outside the Active Management Areas (AMAs). The information presented provides hydrologic background data to support the development of new water adequacy physical availability criteria as required by Senate Bill 1575. This report provides general recommendations for physical availability criteria that will be discussed during the upcoming stakeholder meetings.

Background on S.B. 1575

In many portions of rural Arizona development pressure and population growth is increasing at unprecedented rates that place heavy demands on available water resources. Established water providers, new developers and domestic well owners all share major challenges in finding and developing reliable water supplies. Unfortunately, many of the areas where future development is proposed in rural Arizona do not have abundant or readily accessible water supplies. In recognition of the many issues and challenges that confront the development of sustainable municipal and domestic rural water supplies, legislation (Senate Bill 1575) was passed in 2007 that amended several statutes that related to the sub-division of lands, the sale of lots, the issuance of public reports, and the evaluation of subdivision water supplies.

One of the requirements of S.B. 1575 requires the Arizona Department of Water Resources (ADWR or the Department) to amend its rules adopted pursuant to the evaluation of subdivision water supplies, A.R.S. § 45-108 *et seq*. Among other provisions, S.B. 1575 requires ADWR to amend its rules to establish criteria for demonstrating physically availability of a one hundred-year supply of groundwater or stored water recovered outside the area of impact in specific aquifer systems and groundwater basins and subbasins outside active management areas (AMAs). The criteria may include depth-to-static water level limits or limits based on other physical aquifer characteristics that affect the physical availability of water for a proposed use and shall be appropriate for the groundwater basin or sub-basin (Figure 1).

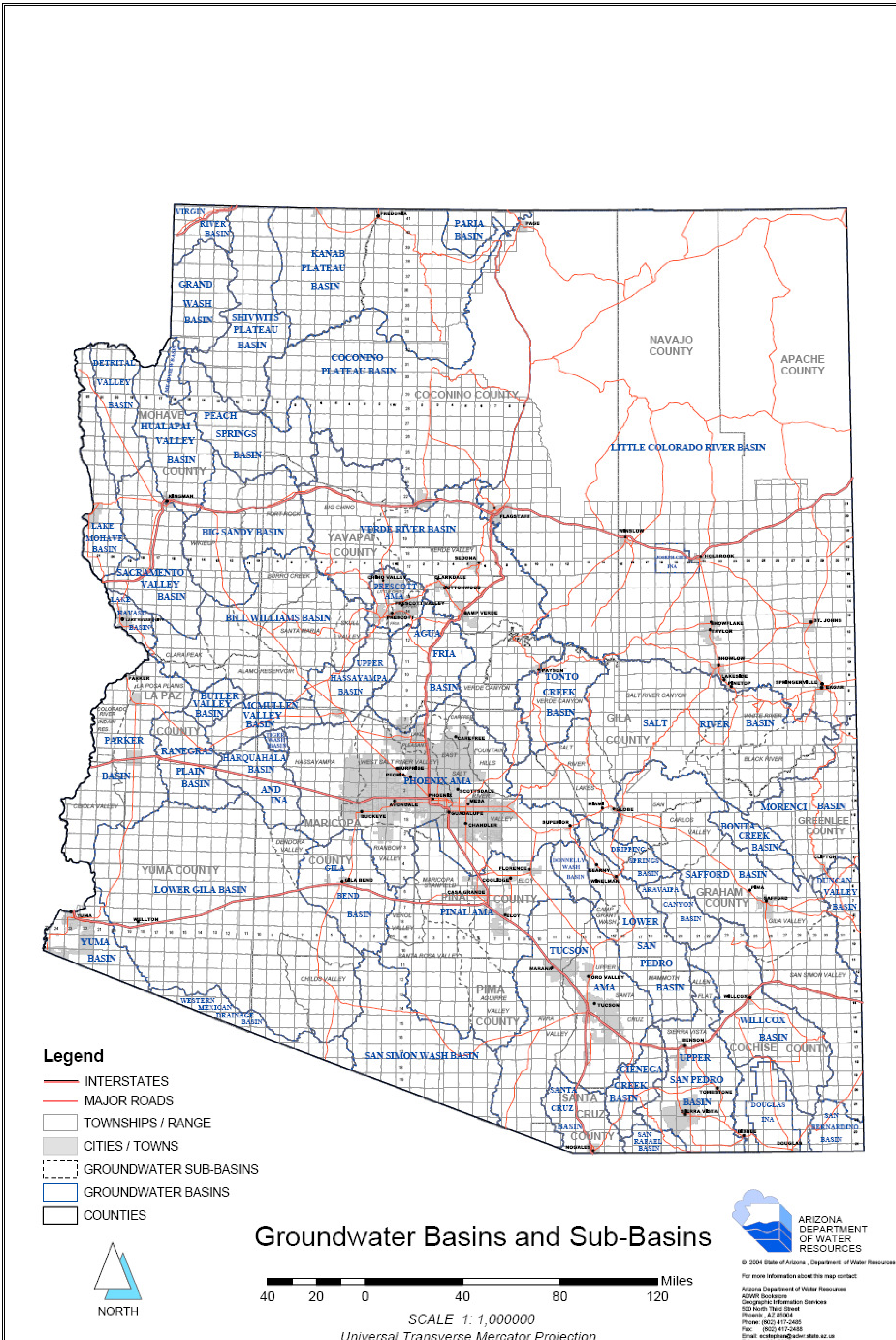

Figure 1 Groundwater Basins and Sub-basins

The rules related to physical availability of groundwater that S.B. 1575 requires the Department to amend are found in A.A.C. R12-15-716. Provisions of the physical availability rule that may require amendment relate to the following:

- requirements of hydrologic studies submitted by applicants to project the maximum 100-year depth-to-static water level in areas outside AMAs
- maximum 100-year depth-to-static water level limits for developments and dry lots outside AMAs
- methods of calculation of the maximum 100-year depth-to-static water level, provisions that allow the lowering of 100-year depth-to-static water level limits outside AMAs

Background on the Existing Depth Criteria for Demonstrating Water Adequacy Outside AMAs

Fundamental to the current rule for demonstrating the physical availability of assured or adequate water supplies in Arizona is the provision that, if groundwater will be withdrawn, projected pumping depths will not exceed applicable maximum 100-year depth-to-static water level limits. The rule, A.A.C. R12-15-716 (B), establishes a 100-year depth-to-static water level limitation of 1,000 feet below land surface (BLS) inside the Phoenix, Prescott and Tucson AMAs (except for dry lot developments). In the Pinal AMA the 100-year depth-to-static water level limitation for developments (except for dry lot developments) is 1,100 feet BLS. Currently the Santa Cruz AMA also has a 100-year depth-to-static water level limit of 1,000-foot BLS. However, new criteria are currently being developed for the Santa Cruz AMA that will require new developments to maintain consistency with the AMA's unique dual goals of maintaining safe-yield and maintaining local water tables from long-term decline. For developments located outside AMAs (except for dry lot developments) the 100-year depth-to-static water level limit is 1,200 feet BLS. The 100-year depth-to-static water level limit for dry lot developments, located anywhere within the state, is 400 feet BLS.

The maximum depth-to-static water level limitations for developments and dry lots date back to 1973 when the state passed laws to protect unwary consumers from developers who sometimes sold land with non-existent or insufficient water supplies. The 1973 legislation required a developer of a subdivision to submit plans for its water supply to the Arizona Water Commission and demonstrate the adequacy of the water supply to the Commission prior to the recordation of the subdivision plat. The 1,200-foot, 100-year, depth-to-static water level limit for subdivisions that was developed in 1973 was based on an evaluation of the maximum pumping depths for municipal water systems throughout the state at that time (Briggs, 2008). As a part of this analysis, it was determined that the City of Flagstaff's pumping from depths of about 1,200 feet BLS at its Woody Mountain well field was about the maximum municipal pumping depth in the state at that time (Briggs, 2008). Similarly, a review of domestic well data from throughout the state revealed that the deepest domestic well pumping was about 400 feet

BLS at that time (Briggs, 2008). Based on the reviews of existing well depths, water levels and pumping depths and also in consideration of well drilling and construction costs, the 400-foot and 1,200-foot depth-to-static water level criteria were established for dry lot subdivisions and subdivision developments with centralized systems throughout the state, respectively.

In 1995, new rules were adopted by ADWR that provided for different 100-year depth-to-static water level criteria depending upon whether a new development was located outside an AMA. Inside AMAs, a new development using groundwater is required to have an "assured" water supply that is consistent with the established 100-year depth-to-static water level requirements for the AMA (see R12-15-716). Outside AMAs, new developments using groundwater may receive an "adequate" or "inadequate" water supply determination depending upon whether they meet the established 100-year depth-to-static water level of 1,200 feet BLS, and other required criteria. In special cases an "adequate" water supply determination may be obtained with a variance if a new development would produce water from a "hardrock" aquifer where the current or projected 100-year depth-to-static water level exceeds the 1,200-foot depth limit if physical availability can be demonstrated below that depth and financial capability to produce the water is also demonstrated. At this time, unless a mandatory adequacy ordinance has been adopted, new developments outside AMAs can still be built with an "inadequate" water supply determination as long as that information is made available through the subdivision's public report to the initial homebuyers in the development. As mentioned previously, the 100-year depth-to-static water level limit for dry lot subdivisions is 400 feet BLS for any location in the state. Since dry lot developments do not have a central water provider, it is assumed that each lot will be served by an individual domestic well. Variances from the 400-foot depth limit for dry lot subdivisions are not allowed because developers cannot generally demonstrate what the financial capability of future lot owners may be to drill at depths that exceed 400 feet BLS (ADWR,2007A).

Current Considerations Regarding Water Adequacy Criteria

As mentioned earlier, the increasing awareness of the special problems and issues that confront water providers and other water users in rural Arizona in finding, developing and producing adequate water supplies resulted in the adoption of the provision in S.B. 1575 that requires ADWR to amend its rules to establish criteria for demonstrating a physically available one hundred-year supply of groundwater or stored water recovered outside the area of impact in specific aquifer systems, and groundwater basins and subbasins outside AMAs. Over the last several months ADWR has considered various approaches to implementing the statutory requirements of S.B. 1575. One approach is to establish new 100-year depth-to-static water adequacy limits for each basin or sub-basin in the state. Another approach consists of establishing specific physical availability criteria for different aquifer types or aquifer conditions outside of AMAs, regardless of the location in the state.

Depth-to-Water and Well Depths

In order to facilitate the identification of locations where specific aquifer types and hydrologic conditions exist, an analysis of current water levels, well information and hydrogeologic data was performed. Essential to the analysis of aquifer conditions was an evaluation of available water level information to help determine areas in the state where groundwater depths currently approach or exceed the 100-year, 1,200-foot BLS depth-to-static water physical availability limit. The evaluation of water level data was conducted using two separate data sources. The first source of data analyzed was the ADWR Groundwater Site Inventory (GWSI) database. The GWSI database is ADWR's scientific groundwater database that contains water level and water quality data collected mainly by the ADWR and USGS throughout the state (Figure 2).

The number of wells with depth-to-water measurements falling within specific depth intervals are summarized by groundwater basin, sub-basin and by county (Tables 1 and 2). In general, the data show that most of the groundwater basins where the depth-to-water approaches or exceeds 1,200 feet BLS are located in the northern part of the state (for example, the Little Colorado River Plateau, Coconino Plateau, Hualapai, Meadview, Peach Springs, Sacramento, Shivwitz and Verde River Basins). The geographic distribution of wells with water level measurements falling within specified depth intervals is shown in Figure 2.

The second source of water level and well data that was analyzed was the ADWR Well Registry database (Wells55). The Wells55 database is the state's official well registry. The database contains various types of well information reported by well owners and well drillers. For this study, the Wells55 database was queried to select only those water production wells that have reported water uses listed as being either for domestic or municipal purposes. Counts were compiled on the number of wells with reported well depths falling within specified depth intervals. Data were compiled by basin, sub-basin and by county (Tables 3-6). From this analysis it was determined that about 75 percent of the registered domestic wells have reported depths that are less 400 feet BLS. The distribution of deeper domestic wells (well depths greater than 400 feet) is most heavily concentrated in the central and southern counties of the state (Maricopa, Pinal, Pima and Cochise counties). However, there are a large number of such wells in Yavapai, Coconino, Mohave, Apache and Navajo counties as well (Table 4). The analysis indicated approximately 56 percent of the registered municipal wells have reported depths that are less than 600 feet BLS (Tables 5 and 6). The data also illustrated that the majority of deeper municipal wells, with depths exceeding 900 feet BLS, are located within the Phoenix and Tucson AMAs. However, on a per capita basis, the highest concentrations of deep municipal wells are found in northern Arizona (Tables 5 and 6).

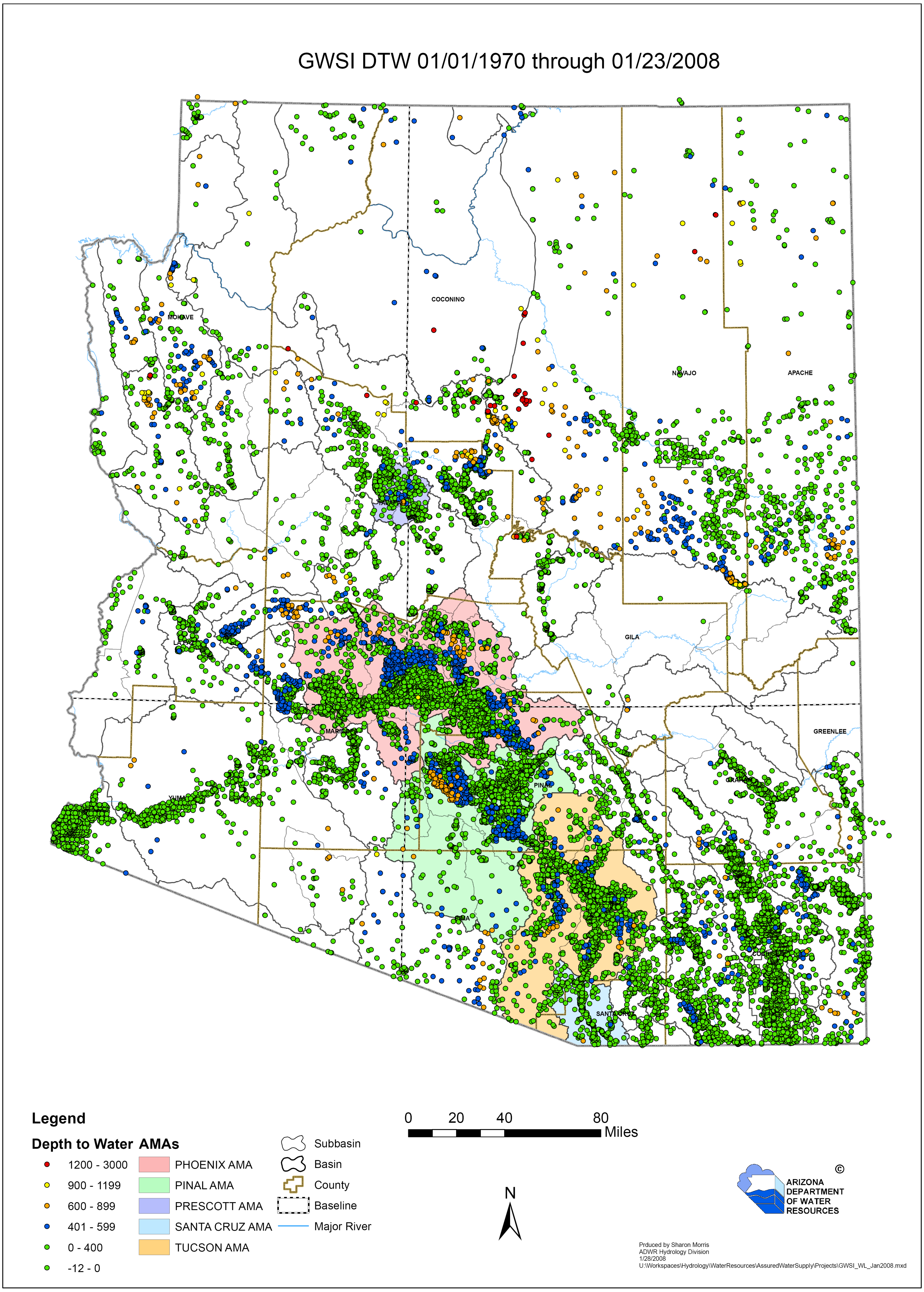

Figure 2 Depth-to-Water in GWSI Wells (1970 to 2008)

Information on the reported depth-to-water at the time of drilling was also compiled from the Wells55 database (Tables 7 and 8). Reported depths to water that were less than or equal to zero or greater than 3,000 feet BLS were generally found to be inaccurate and were not used in the calculation of means. It should be noted that reported depth-to-water data at the time of drilling are generally not considered to be a highly reliable data source for most types of quantitative hydrologic analysis; however it is presented in this report to provide a general impression of typical depths-to-water in various areas of the state. Mean values for some basins were based on sparse data and were found to be very inconsistent with GWSI water level data for those areas. In such cases the mean values were not shown in the tables.

Tables 7 and 8 list the mean reported depth-to-water at the time of drilling for domestic and municipal wells compiled by basin, sub-basin and county. The data indicate that the mean reported depth-to-water at the time of drilling ranged from less than 50 feet to over 600 feet BLS in various sub-basins throughout the state.

Table 1 Number of Wells With Depth-To-Water Within Specified Depth Intervals (compiled by basin and subbasin)

Table 1
(Depth-to-Water Data Compiled From ADWR GWSI Database for Period 1970-2008)

Basin	Subbasins within Basin	DTW 0'-400'	DTW 401'-599'	DTW 600'-899'	DTW 900'-1,200'	DTW >1,200'	Total Count
Agua Fria		91	1	0	0	0	92
Aravaipa Canyon		42	1	1	0	0	44
Big Sandy	Fort Rock	10	5	3	1	0	19
	Wikieup	78	3	2	0	0	83
Bill Williams	Alamo Reservoir	18	1	3	0	0	22
	Burro Creek	4	0	0	0	0	4
	Clara Peak	18	0	0	0	0	18
	Santa Maria	27	0	0	0	0	27
	Skull Valley	51	3	0	0	0	54
Bonita Creek		0	0	0	0	0	0
Butler Valley		26	3	1	0	0	30
Cienega Creek		162	3	0	0	0	165
Coconino Plateau		21	6	0	1	1	29
Detrital Valley		33	11	5	0	0	49
Donnelly Wash		24	0	0	0	0	24
Douglas	Douglas	785	1	0	0	0	786
	Douglas INA	7	0	0	0	0	7
Dripping Springs Wash		26	0	0	0	0	26
Duncan Valley		102	3	0	0	0	105
Gila Bend		240	8	2	0	0	250
Grand Wash		2	1	2	0	0	5
Harquahala	Harquahala INA	154	90	2	0	0	246
Hualapai Valley		43	36	17	2	0	98
Kanab	Kanab Plateau	45	7	1	0	0	53
Lake Havasu		1	0	0	0	0	1
Lake Mohave		28	1	0	0	0	29
Little Colorado River Plateau	Little Colo. River	1086	141	88	26	26	1367
	Joseph City INA	42	0	0	0	0	42
Lower Gila	Childs Valley	20	1	4	0	0	25
	Dendora Valley	33	0	0	0	0	33
	Wellton-Mohawk	497	5	3	0	0	505
Lower San Pedro	Camp Grant Wash	34	0	0	0	0	34
	Mammoth	276	10	1	0	0	287
McMullen Valley		60	95	17	0	0	172
Meadview		3	14	2	2	0	21
Morenci		29	0	0	0	0	29
Paria		5	4	1	0	0	10
Parker	Cibola Valley	3	0	0	0	0	3
	Colo. River Indian	21	0	0	0	0	21
	La Posa Plains	53	7	0	0	0	60
Peach Springs		21	2	1	0	1	25
Phoenix AMA	East SRV	1095	170	29	0	0	1294
	West SRV	1227	229	4	1	0	1461
	Fountain Hills	53	1	1	0	0	55
	Hassayampa	500	33	4	0	0	537
	Rainbow Valley	76	20	0	0	0	96
	Carefree	66	2	0	0	0	68
	Lake Pleasant	72	0	0	0	0	72

Table 1 (continued) (Depth-to-Water Data Compiled From ADWR GWSI Database for Period 1970-2008)							
Basin	Subbasins within Basin	DTW 0'-400'	DTW 401'-599'	DTW 600'-899'	DTW 900'-1,200'	DTW >1,200'	Total Count
Pinal AMA	Aguirre Valley	30	5	1	0	0	36
	Eloy	1404	91	2	0	0	1497
	Maricopa-Stanfield	373	173	54	0	0	600
	Santa Rosa Valley	54	1	2	0	0	57
	Vekol Valley	37	5	1	0	0	43
Prescott AMA	Upper Agua Fria	168	5	5	0	0	178
	Little Chino Valley	233	13	0	0	0	246
Ranegras Plain		201	7	0	0	0	208
Sacramento Valley		146	12	13	10	2	183
Safford	Gila Valley	348	2	1	0	0	351
	San Carlos Valley	1	3	2	0	0	6
	San Simon Valley	486	33	1	0	0	520
Salt River	Black River	4	0	0	0	0	4
	Salt River Canyon	4	1	0	0	0	5
	Salt River Lakes	7	0	0	0	0	7
	White River	3	0	0	0	0	3
San Bernadino Valley		57	5	6	0	0	68
San Rafael		55	0	0	0	0	55
San Simon Wash		88	33	12	1	0	134
Santa Cruz AMA		326	1	1	0	0	328
Shivwits Plateau		5	0	0	1	0	6
Tiger Wash		5	0	0	0	0	5
Tonto Creek		162	0	0	0	0	162
Tucson AMA	Avra Valley	491	74	10	0	0	575
	Upper Santa Cruz	1640	66	5	0	0	1711
Upper Hassayampa		111	3	5	1	0	120
Upper San Pedro	Allen Flats	23	1	1	0	0	25
	Sierra Vista	967	64	2	0	0	1033
Verde River	Big Chino	245	10	2	4	2	263
	Verde Valley	1163	69	36	5	1	1274
	Verde Canyon	102	0	2	0	1	105
Virgin River		50	0	1	0	0	51
Western Mexican Drainage		11	0	0	0	0	11
Willcox		1308	41	6	0	0	1355
Yuma		660	1	0	0	0	661
	Total Count →	18278	1637	365	55	34	20369

Table 2 Number of wells With Depth-to-Water Within Specified Intervals (compiled by county)

Table 2.

(Depth-to-Water Data Compiled From ADWR GWSI Database for Period 1970-2008)

Counties	DTW 0'-400'	DTW 401'-599'	DTW 600'-899'	DTW 900'-1,200'	DTW >1,200'	Total Count
Apache	477	30	27	4	0	538
Cochise	3458	131	14	0	0	3603
Coconino	430	57	55	21	28	591
Gila	304	4	3	0	1	312
Graham	549	19	5	0	0	573
Greenlee	106	3	0	0	0	109
La Paz	384	100	3	0	0	487
Maricopa	3426	512	56	1	0	3995
Mohave	468	81	42	15	2	608
Navajo	466	81	29	5	2	583
Pima	2359	169	32	1	0	2561
Pinal	2399	336	63	0	0	2798
Santa Cruz	482	3	1	0	0	486
Yavapai	1872	105	33	8	1	2019
Yuma	1097	6	2	0	0	1105
Total Count →	18277	1637	365	55	34	20368

Table 3 Reported Depth Ranges for Registered Domestic Wells (compiled by basin and subbasin)

Table 3

(Well Depth Data Compiled From ADWR Wells55 Database through 1/2008)

Basin	Subbasins within Basin	Well Depth 0'-400'	Well Depth 401'-600'	Well Depth > 601'	Total Count
Agua Fria		1480	231	70	1781
Aravaipa Canyon		102	1	1	104
	Fort Rock	181	54	71	306
Big Sandy	Wikieup	626	101	162	889
	Alamo Reservoir	72	12	2	86
	Burro Creek	40	22	11	73
	Clara Peak	34	1	0	35
	Santa Maria	210	12	4	226
Bill Williams	Skull Valley	636	78	41	755
Bonita Creek		15	1	0	16
Butler Valley		4	1	2	7
Cienega Creek		1370	336	47	1753
Coconino Plateau		167	14	19	200
Detrital Valley		29	21	67	117
Donnelly Wash		40	7	5	52
	Douglas	1570	140	25	1735
Douglas	Douglas INA	0	0	0	0
Dripping Springs Wash		112	4	3	119
Duncan Valley		845	10	3	858
Gila Bend		103	23	22	148
Grand Wash		2	1	0	3
Harquahala	Harquahala INA	63	28	79	170
Hualapai Valley		515	149	295	959
Kanab	Kanab Plateau	144	7	7	158
Lake Havasu		110	5	3	118
Lake Mohave		2047	62	29	2138
	Little Colo. River	6191	1275	835	8301
Little Colorado River Plateau	Joseph City INA	109	11	3	123
	Childs Valley	24	3	6	33
	Dendora Valley	8	0	1	9
Lower Gila	Wellton-Mohawk	582	49	39	670
	Camp Grant Wash	44	15	6	65
Lower San Pedro	Mammoth	1148	91	40	1279
McMullen Valley		189	79	139	407
Meadview		4	1	12	17
Morenci		435	35	8	478
Paria		1	0	4	5
	Cibola Valley	166	7	4	177
	Colo. River Indian	22	2	0	24
Parker	La Posa Plains	1384	36	100	1520
Peach Springs		12	6	10	28
	East SRV	2511	1779	1155	5445
	West SRV	2691	1135	871	4697
	Fountain Hills	85	337	419	841
	Hassayampa	1737	316	114	2167
	Rainbow Valley	35	91	25	151
	Carefree	537	85	47	669
Phoenix AMA	Lake Pleasant	594	170	56	820

Table 3 (continued)

(Well Depth Data Compiled From ADWR Wells55 Database through 1/2008)

Basin	Subbasins within Basin	Well Depth 0'-400'	Well Depth 401'-600'	Well Depth > 601'	Total Count
	Aguirre Valley	9	12	1	22
	Eloy	821	433	283	1537
	Maricopa-Stanfield	143	213	430	786
	Santa Rosa Valley	1	0	2	3
Pinal AMA	Vekol Valley	15	1	2	18
	Upper Agua Fria	2266	432	620	3318
Prescott AMA	Little Chino Valley	5733	2379	0	8112
Ranegras Plain		465	91	24	580
Sacramento Valley		625	222	225	1072
	Gila Valley	1636	16	0	1652
	San Carlos Valley	78	20	21	119
Safford	San Simon Valley	602	92	66	760
	Black River	18	5	0	23
	Salt River Canyon	592	12	8	612
	Salt River Lakes	598	87	58	743
Salt River	White River	11	1	0	12
San Bernadino Valley		60	4	3	67
San Rafael		106	9	5	120
San Simon Wash		7	1	0	8
Santa Cruz AMA		954	127	48	1129
Shivwits Plateau		4	0	0	4
Tiger Wash		1	0	0	1
Tonto Creek		2149	36	17	2202
	Avra Valley	1036	684	0	1720
Tucson AMA	Upper Santa Cruz	3652	1033	609	5294
Upper Hassayampa		1459	340	91	1890
	Allen Flats	19	4	0	23
Upper San Pedro	Sierra Vista	4222	647	468	5337
	Big Chino	2420	508	0	2928
	Verde Valley	7474	493	360	8327
Verde River	Verde Canyon	1166	64	13	1243
Virgin River		318	51	7	376
Western Mexican Drainage		7	4	0	11
Willcox		2780	465	1580	4825
Yuma		2916	10	7	2933
Total Count →		73389	15340	9810	98539

* Well counts compiled by "basin and subbasin" vary slightly from counts compiled by "county" because of inconsistencies in the Wells55-database.

Table 4 Reported Depth Ranges for Registered Domestic Wells (compiled by county)

Table 4 (Well Depth Data Compiled From ADWR Wells 55 Database through 1/2008)					
Counties	Number of Domestic Wells with Depth 0'-400'	Number of Domestic Wells with Depth 401'- 600'	Number of Domestic Wells with Depth > 600'	Total Count	Average Domestic Well Depth (Feet)
Apache	2994	405	249	3648	292
Cochise	9120	1441	735	11296	297
Coconino	1864	252	324	2440	338
Gila	4642	223	110	4975	196
Graham	1821	50	39	1910	153
Greenlee	951	16	7	974	148
La Paz	2264	225	177	2666	220
Maricopa	8462	3552	2565	14579	422
Mohave	4745	696	855	6296	306
Navajo	2877	756	385	4018	361
Pima	5136	1759	774	7669	381
Pinal	2955	1418	1233	5606	452
Santa Cruz	2135	261	67	2463	261
Yavapai	20516	4349	1083	25948	296
Yuma	3515	50	35	3600	167
Total Count →	73997	15453	8638	98088	

* Well counts compiled by "basin and subbasin" vary slightly from counts compiled by "county" because of inconsistencies in the Wells55-database.

Table 5 Reported Depth Ranges for Registered Municipal Wells (compiled by basin and subbasin)

Table 5 (Well Depth Data Compiled From ADWR Wells55 Database through 1/2008)						
Basin	Subbasins within Basin	Well Depth 0'- 600'	Well Depth 601'-900'	Well Depth 901'-1,200'	Well Depth > 1,200'	Total Count
Agua Fria		58	2	1	1	62
Aravaipa Canyon		0	0	0	0	0
	Fort Rock	0	0	0	0	0
Big Sandy	Wikieup	6	0	0	0	6
	Alamo Reservoir	1	0	0	0	1
	Burro Creek	7	3	0	0	10
	Clara Peak	3	0	0	0	3
	Santa Maria	4	0	0	0	4
Bill Williams	Skull Valley	2	0	2	1	5
Bonita Creek		12	0	0	0	12
Butler Valley		0	0	0	0	0
Cienega Creek		11	0	0	0	11
Coconino Plateau		16	1	0	5	22
Detrital Valley		6	4	2	0	12
Donnelly Wash		0	0	0	0	0
	Douglas	21	3	0	0	24
Douglas	Douglas INA	0	0	0	0	0
Dripping Springs Wash		0	0	0	0	0
Duncan Valley		13	2	0	0	15
Gila Bend		5	1	3	3	12
Grand Wash		0	0	0	0	0
Harquahala	Harquahala INA	3	3	6	2	14
Hualapai Valley		16	2	17	1	36
Kanab	Kanab Plateau	7	0	0	1	8
Lake Havasu		23	2	1	0	26
Lake Mohave		34	4	4	3	45
	Little Colo. River	131	31	19	29	210
Little Colorado River Plateau	Joseph City INA	1	0	0	0	1
	Childs Valley	0	3	4	2	9
	Dendora Valley	0	0	0	0	0
Lower Gila	Wellton-Mohawk	21	0	0	0	21
	Camp Grant Wash	0	0	0	0	0
Lower San Pedro	Mammoth	24	1	1	3	29
McMullen Valley		5	9	0	2	16
Meadview		4	8	1	0	13
Morenci		11	1	0	0	12
Paria		0	0	0	0	0
	Cibola Valley	1	0	0	0	1
	Colo. River Indian	4	0	0	0	4
Parker	La Posa Plains	16	1	2	2	21
Peach Springs		2	1	1	0	4
	East SRV	141	102	143	110	496
	West SRV	216	170	129	108	623
	Fountain Hills	3	8	11	1	23
	Hassayampa	18	10	4	7	39
	Rainbow Valley	1	0	0	0	1
	Carefree	12	4	11	0	27
Phoenix AMA	Lake Pleasant	4	1	0	1	6

Table 5 (continued) **(Well Depth Data Compiled From ADWR Wells55 Database through 1/2008)**						
Basin	Subbasins within Basin	Well Depth 0'- 600'	Well Depth 601'-900'	Well Depth 901'-1,200'	Well Depth > 1,200'	Total Count
	Aguirre Valley	1	1	0	0	2
	Eloy	28	16	37	13	94
	Maricopa-Stanfield	12	15	9	1	37
	Santa Rosa Valley	0	0	0	0	0
Pinal AMA	Vekol Valley	1	0	0	0	1
	Upper Agua Fria	25	11	8	1	45
Prescott AMA	Little Chino Valley	47	10	2	0	59
Ranegras Plain		4	0	0	0	4
Sacramento Valley		15	3	8	4	30
	Gila Valley	40	4	0	0	44
	San Carlos Valley	0	0	4	0	4
Safford	San Simon Valley	3	2	3	0	8
	Black River	0	0	0	0	0
	Salt River Canyon	0	2	0	0	2
	Salt River Lakes	14	12	10	1	37
Salt River	White River	0	0	1	0	1
San Bernadino Valley		0	0	0	0	0
San Rafael		0	0	0	0	0
San Simon Wash		0	0	0	0	0
Santa Cruz AMA		68	5	0	0	73
Shivwits Plateau		1	0	0	0	1
Tiger Wash		0	0	0	0	0
Tonto Creek		63	10	5	0	78
	Avra Valley	81	59	61	3	204
Tucson AMA	Upper Santa Cruz	544	155	70	5	774
Upper Hassayampa		20	0	0	1	21
	Allen Flats	0	0	0	0	0
Upper San Pedro	Sierra Vista	69	15	21	3	108
	Big Chino	18	3	0	2	23
	Verde Valley	89	34	17	22	162
Verde River	Verde Canyon	136	21	2	1	160
Virgin River		5	0	3	0	8
Western Mexican Drainage		0	0	0	0	0
Willcox		21	8	2	0	31
Yuma		40	5	0	0	45
Total Count →		2208	768	625	339	3940

* Well counts compiled by "basin and subbasin" vary slightly from counts compiled by "county" because of inconsistencies in the Wells55-database.

Table 6 Reported Depth Ranges for Registered Municipal Wells (compiled by county)

Table 6

(Well Depth Data Compiled From ADWR Wells 55 Database through 1/2008)

Counties	Number of Municipal Wells with Depth <= 600’	Number of Municipal Wells with Depth 601’- 900’	Number of Municipal Wells with Depth 901’-1,200’	Number of Municipal Wells with Depth > 1,200’	Total Count	Average Municipal Well Depth (Feet)
Apache	58	10	4	2	74	424
Cochise	116	28	26	3	173	580
Coconino	53	19	12	45	129	1002
Gila	217	43	21	2	283	436
Graham	52	4	0	0	56	190
Greenlee	16	2	0	0	18	307
La Paz	33	5	3	4	45	427
Maricopa	406	291	295	224	1216	872
Mohave	122	25	37	9	193	550
Navajo	72	13	9	1	95	480
Pima	620	210	129	7	966	567
Pinal	75	53	64	27	219	839
Santa Cruz	79	5	1	0	85	294
Yavapai	239	58	25	15	337	513
Yuma	59	5	0	0	64	310
Total Count →	2217	771	626	339	3953	

* Well counts compiled by “basin and subbasin” vary slightly from counts compiled by “county” because of inconsistencies in the Wells55-database.

Table 7 Mean Reported Depth-to-Water at Time of Drilling for Registered Domestic and Municipal Wells (compiled by basin and subbasin)

Table 7

(Depth-to-Water Data Compiled From ADWR Wells55 Database through 1/2008)

Basin	Subbasins within Basin	Mean Reported DTW for " Domestic Wells" (Feet-BLS)	Mean Reported DTW for "Municipal Wells" (Feet-BLS)
Agua Fria		84	67
Aravaipa Canyon		68	
Big Sandy	Fort Rock	286	
	Wikieup	202	98
Bill Williams	Alamo Reservoir	113	
	Burro Creek	191	163
	Clara Peak	72	83
	Santa Maria	68	59
	Skull Valley	95	280
Bonita Creek		31	27
Butler Valley		215	
Cienega Creek		170	108
Coconino Plateau		139	
Detrital Valley		496	267
Donnelly Wash		121	
Douglas	Douglas	112	174
	Douglas INA		
Dripping Springs Wash		46	
Duncan Valley		68	199
Gila Bend		191	288
Grand Wash			
Harquahala	Harquahala INA	377	466
Hualapai Valley		290	350
Kanab	Kanab Plateau	86	130
Lake Havasu		100	85
Lake Mohave		67	244
Little Colorado River Plateau	Little Colo. River	223	400
	Joseph City INA	124	
Lower Gila	Childs Valley	170	601
	Dendora Valley	73	
	Wellton-Mohawk	86	94
Lower San Pedro	Camp Grant Wash	149	
	Mammoth	79	70
McMullen Valley		321	336
Meadview		633	
Morenci		63	120
Paria		600	
Parker	Cibola Valley	39	20
	Colo. River Indian	39	53
	La Posa Plains	95	110
Peach Springs		291	134
Phoenix AMA	East SRV	244	289
	West SRV	215	239
	Fountain Hills	415	278
	Hassayampa	162	208
	Rainbow Valley	320	380
	Carefree	129	199
	Lake Pleasant	100	130

Table 7 (continued) (Depth-to-Water Data Compiled From ADWR Wells55 Database through 1/2008)			
Basin	Subbasins within Basin	Mean Reported DTW for " Domestic Wells" (Feet-BLS)	Mean Reported DTW for "Municipal Wells" (Feet-BLS)
Pinal AMA	Aguirre Valley	256	173
	Eloy	245	261
	Maricopa-Stanfield	440	330
	Santa Rosa Valley	35	
	Vekol Valley	189	295
Prescott AMA	Upper Agua Fria	108	173
	Little Chino Valley	178	156
Ranegras Plain		148	60
Sacramento Valley		238	286
Safford	Gila Valley	46	54
	San Carlos Valley	192	504
	San Simon Valley	153	296
Salt River	Black River	119	
	Salt River Canyon	83	600
	Salt River Lakes	89	365
	White River	93	695
San Bernadino Valley		107	
San Rafael		82	
San Simon Wash		84	
Santa Cruz AMA		122	82
Shivwits Plateau			
Tiger Wash		200	
Tonto Creek		59	58
Tucson AMA	Avra Valley	244	307
	Upper Santa Cruz	194	175
Upper Hassayampa		154	98
Upper San Pedro	Allen Flats		
	Sierra Vista	157	229
Verde River	Big Chino	171	196
	Verde Valley	101	251
	Verde Canyon	88	96
Virgin River		166	248
Western Mexican Drainage		157	
Willcox		150	152
Yuma		44	94

* Wells with reported DTW ≤ 0 or DTW >3,000 feet BLS were not used in the calculation of mean values. Mean values for some basins were based on sparse data and were not shown in the tables.

Table 8 Mean Reported Depth-to-Water at Time of Drilling for Registered Domestic and Municipal Wells (compiled by county)

Table 8 **(Water Level Data Compiled From ADWR Wells55 Database through 1/2008)**		
Counties	Mean Reported DTW for" Domestic Wells" (Feet-BLS)	Mean Reported DTW for "Municipal Wells" (Feet-BLS)
Apache	157	192
Cochise	152	215
Coconino	213	
Gila	74	128
Graham	57	48
Greenlee	67	177
La Paz	121	154
Maricopa	216	255
Mohave	174	221
Navajo	248	295
Pima	201	203
Pinal	242	284
Santa Cruz	118	80
Yavapai	137	164
Yuma	51	96

* Wells with reported DTW < = 0 or DTW >3,000 feet BLS were not used in the calculation of mean values. Mean values for some basins were based on sparse data and were not shown in the tables.

Variance Options Related to Physical Availability Demonstrations

The data shown in Tables 1 through 8 indicate that the depth-to-water currently approaches or exceeds 1,200 feet BLS in many parts of central and northern Arizona. Therefore, many new subdivisions in such areas are unable to demonstrate physical availability under the current water adequacy rules, unless they qualify for and receive a variance. However, few variances have actually been granted to exceed the 100-year, 1,200 foot BLS water adequacy physical availability limit.

The reasons that few variances have been granted include:

1) the inability on the part of the developer to demonstrate with any acceptable level of certainty that an adequate and sustainable water supply exists, regardless of depth;
2) the developer cannot demonstrate the financial capability to develop such a water supply.

While the Department may continue to consider variance requests to allow the projected 100-year depth-to-water to exceed the 1,200 foot depth limitation for physical availability on a case-by-case basis, S.B. 1575 authorizes ADWR to modify the physical availability criteria to allow different standards for different aquifer types and locations. The following sections present information on this topic.

Aquifer Types

As mentioned previously, S.B. 1575 requires that criteria be established to demonstrate physical availability for specific aquifer systems and groundwater basins and subbasins outside active management areas. In order to develop these criteria, ADWR has considered the general types of aquifer systems from which groundwater is commonly produced throughout the state. The specific types of aquifer systems that were considered include: basin-fill (alluvial or lacustrine) aquifers, consolidated sedimentary rock (sandstone, siltstone, limestone, etc.) aquifers and volcanic and crystalline bedrock aquifers.

The distribution of aquifer types throughout the state is closely related to the physiographic provinces or regions of the state (Figure 3). In the Basin and Range Province of southern and western Arizona groundwater is generally produced from large, deep alluvial aquifer systems that commonly cover hundreds of square miles and often have thicknesses of several thousand feet. However, in some portions of the Basin and Range Province, groundwater is also produced from consolidated sedimentary rocks, volcanic rocks and fractured or decomposed crystalline bedrock. In the Central Highlands Province that forms a Transition Zone between the Basin and Range and Colorado Plateau provinces (Figure 3), groundwater is produced from a combination of smaller-scale basin-fill aquifer systems, consolidated sedimentary rocks, volcanic rocks and fractured or decomposed crystalline bedrock. In the Colorado Plateau Province (Figure 3) the regional aquifer system covers thousands of square miles and is generally composed of consolidated sedimentary rocks and volcanic rocks that may be several hundred to several thousand feet in thickness. However, on a local level, groundwater may also be produced from alluvial deposits and from fractured or decomposed crystalline bedrock. It should be noted that groundwater is also produced in localized zones within each physiographic province from perched aquifer systems that are highly reliant on recharge and are not generally considered reliable as a long-term water supply.

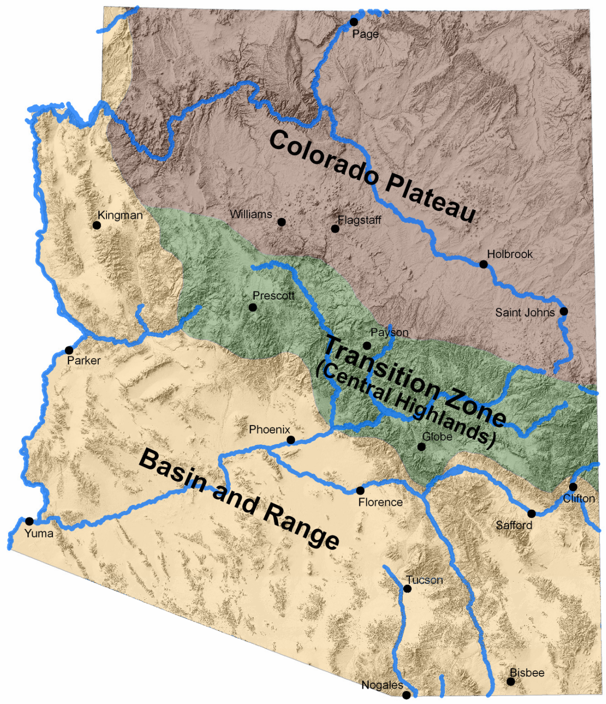

Figure 3 Physiographic Provinces of Arizona

<u>Basin-Fill Aquifer Systems</u>

Large, deep basin-fill aquifer systems cover much of the southern and western portions of the state (Figure 3). Basin-fill aquifer systems are also found in some portions of central Arizona. Based on the depth-to-water data shown in Tables 1, 2 and 7 it is apparent that depths to groundwater are generally well above 1,200 feet BLS in most of the basin-fill aquifer systems of the state. However, the depth-to-water approaches or exceeds 1,200 feet BLS in many of the alluvial groundwater basins located in northwestern Arizona. For example, annual groundwater levels measured in some ADWR groundwater monitoring "index" wells located in the Sacramento, Hualapai, Detrital, Meadview, Shivwitz Plateau basins exceed 900 feet BLS. Measured depth-to-water exceeds 1,200 feet BLS in two municipal wells in the Sacramento basin and one well in the Peach Springs basin (Table 1). Reported depths for municipal wells in those basins commonly exceed 900 feet BLS (Table 5).

Figure 4 shows the primary aquifer types for selected wells located in the Detrital, Hualapai and Sacramento basins (Anning, and others, 2007). Although groundwater is produced from a variety of aquifer types, most of the wells reviewed produce water from unconsolidated to semi-consolidated alluvial deposits that may exceed 5,000 feet in thickness in the centers of the basins (Anning, and others, 2005) (Conway and Ivanich, 2006 and 2007). Some groundwater is also produced from volcanic rocks in the Kingman area (Anning, and others, 2007). The basin-fill alluvial sediments are divided into older, intermediate and younger alluvium (Anning, and others, 2007). However, the principal aquifer in these basins is the older alluvium because the intermediate and younger alluvium is generally above the water table (Anning, and others, 2007).

Groundwater flow in the Detrital and Hualapai basins is generally from points of recharge along the mountain fronts of the basins toward the basin centers and then generally northward along the basin axes toward Lake Mead. Similar recharge and flow patterns occur in the Sacramento basin, however the flow along the basin axis is generally directed to the southwest toward the Colorado River (Anning, and others 2007).

Figure 4 Aquifer types for selected wells in the Detrital, Hualapai and Sacramento basins (figure from USGS SIR 2007-5182)

Consolidated Sedimentary Rock Aquifer Systems

Regionally extensive consolidated sedimentary rock aquifers are found throughout most of the Colorado Plateau region of Arizona (Figure 3). Consolidated sedimentary rock aquifers are also found in some portions of the Central Highlands region of the state and in portions of southern Arizona. Data indicate that water levels approach or exceed 1,200 feet BLS in many parts of the consolidated sedimentary rock aquifers of northern and central Arizona (Table 1). For example, the measured depth-to-water approaches or exceeds 1,200 feet BLS in the Coconino Plateau, Little Colorado River Plateau, and Verde River basins. Reported municipal well depths in those basins commonly exceed 900 feet with many wells having total depths in excess of 1,200 feet BLS.

A generalized hydrogeologic cross-section of the Verde Valley and Coconino Plateau showing the major aquifer units is shown in Figure 5.

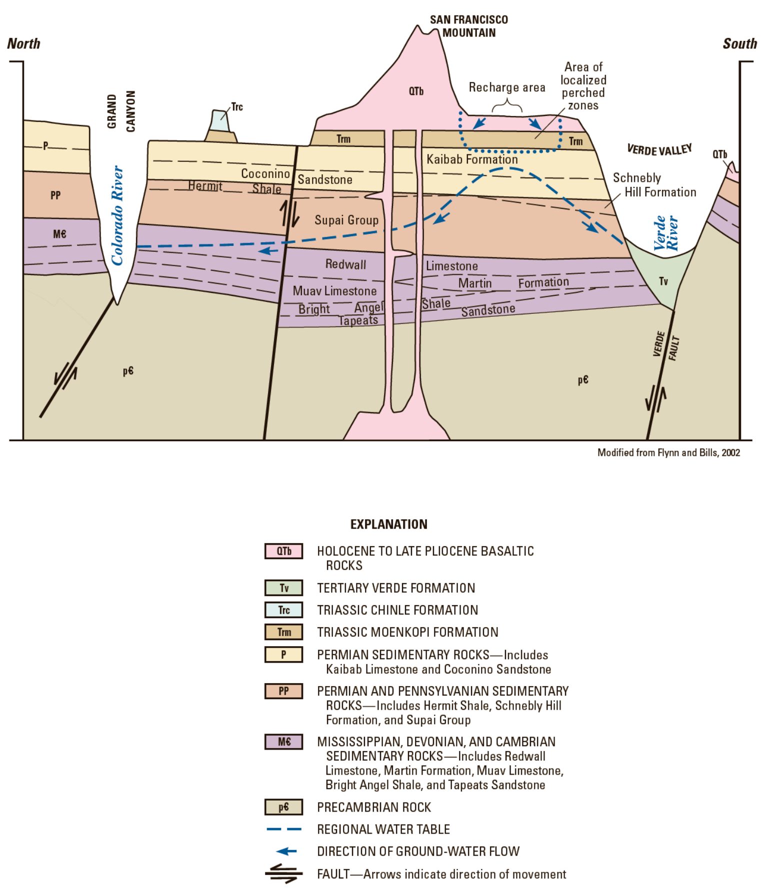

Figure 5 Generalized Hydrogeologic Cross-Section in the Coconino Plateau and Verde Valley (figure from USGS SIR 2005-5198)

"C aquifer"

The principal aquifer system in most of northern Arizona is the "C aquifer" that is generally described as the sequence of rock units between the Kaibab Formation and Supai Group, inclusive. In the Flagstaff and Sedona area, the C aquifer is comprised of Kaibab Limestone, the Coconino Sandstone, the Schnebly Hill Formation and the upper and middle Supai Formations and yields substantial amounts of groundwater to those municipalities (Bills, and others, 2005). The C aquifer is also a principal source of water to the east of Flagstaff in a large part of the Little Colorado River basin (Overby, 2007). The geologic units that comprise the C aquifer are generally unsaturated a few miles west of Flagstaff (Bill, and others, 2005). The productivity of the consolidated sedimentary rocks of the C aquifer system is directly related to the primary and secondary porosity and permeability of the sedimentary rocks. The most productive water bearing materials tend to be fine to medium-grained sandstones, and ground-water flow and well yields are related to geologic structure. Fracturing associated with structural deformation increases recharge locally and also increases the potential for high well yields (Bills, and others, 2000). North and west of Flagstaff the upper units of the C aquifer abruptly become unsaturated; further west the aquifer is completely unsaturated (Bills, and others, 2005). Well yields from wells developed in the C aquifer system in the Coconino Plateau area vary from 1 to 1,700 gallons per minute (gpm) (Bills, and others, 2005). According to Bills (2005), the primary factors affecting well yields are:

- Formation lithology
- Degree and type of fracturing
- Degree of secondary mineralization of the aquifer
- Saturated thickness penetrated by the well
- Well efficiency
- Pump design and lift

Sources of recharge to the C aquifer system in the Coconino Plateau are from direct infiltration of rainfall and snowmelt, mainly at higher altitudes along the Mogollon Rim and the San Francisco Peaks area. The C aquifer is also recharged from downward leakage of groundwater from perched zones and through volcanic rocks (Bills, and others, 2005). Some recharge is also derived from the infiltration of treated municipal effluent and as groundwater underflow from areas farther to the east. Groundwater discharge from the C aquifer occurs as springflow to the Verde Valley, underflow to the aquifers of the Verde Valley, downward leakage to the Redwall-Mauv aquifer, discharge from wells, and evapotranspiration where the water table is shallow (Bills, and others, 2005).

"R Aquifer"

Underlying the C aquifer system is the Redwall-Mauv "R aquifer" system (Bills, and others, 2005). The R aquifer system is also known as the limestone aquifer and is comprised mainly of the carbonate rocks of the Redwall, Temple Butte (Martin) and Mauv formations. The underlying Bright Angel Shale and Tapeats Sandstone are also included in the R aquifer system (McGavock, and others, 1986). The R aquifer forms a regionally extensive aquifer system that underlies a large portion of the Colorado Plateau, the Verde Valley, and the Big Chino sub-basin. On a regional basis, only modest amounts of groundwater have been produced from the R aquifer, mainly due to the prohibitive cost of drilling to deep depths and because shallower alternative water supplies are often available. However, locally important supplies of groundwater are produced from the R aquifer in the Sedona, Clarkdale, Paulden, Williams and Valle areas. In most areas of the Colorado Plateau the R aquifer is saturated, but it has generally not been exploited, as yet, because there is often a more reliable, less expensive source of water to produce. However, as growth pressures increase throughout the region more focus and attention will to be given to the water production potential of the R aquifer. Aquifer properties of the R aquifer are largely uncharacterized due to the lack of deep wells that penetrate the system. Although the data are sparse, it is clear that water production from the R aquifer is dependent upon formation lithology and geologic structure (Bills, and others 2005). Structural development (faulting and fracturing) results in secondary permeability that greatly influences the occurrence and movement of groundwater in the aquifer (Bills, and others, 2005). Wells drilled along the extension of faults and fractures typically penetrate zones of increased transmissivity owing to the solution-enhanced permeability (Montgomery, and Assoc., 1999). Yields of wells in the R aquifer system range from less than 1 gpm to more than 1,000 gpm (Bills, and others, 2005). The same factors that control well yields in the C aquifer system also contribute to the large range of well yields in the R aquifer system. However, the dissolution of limestone and the widening of fractures by dissolution contribute significantly to the large range of well yields (Bills, and others, 2005).

In the Coconino Plateau area, recharge to the R aquifer occurs almost entirely through faults, fractures and other geologic structures, or by downward leakage from overlying units (Bills, and others, 2005). The R aquifer may receive recharge as underflow from the Black Mesa and Little Colorado River Plateau area; however this possibility seems less likely because most of the underflow from the east may be discharged to the Little Colorado River or is impeded by the structural uplift of impermeable crystalline basement granites along the Mesa Butte Fault (Bills, and others, 2005).

Groundwater discharge from the R aquifer occurs as spring flow along the lower Little Colorado River and its tributaries of the Colorado River along the south rim of the Grand Canyon, springflow along the Verde river and its tributaries, underflow to the Verde Valley, downward leakage to the Bright Angel Shale and the Tapeats Sandstone, discharge from wells and evapotranspiration where the water table in the aquifer is near land surface (Bills, and others, 2005).

Volcanic and Crystalline Bedrock Aquifer Systems

Water-bearing volcanic rocks are found in many areas of the state. Volcanic rocks that contain inner-connected cavities and conduits or interbeds of permeable material can be productive aquifers. Fracturing and faulting can also significantly enhance the permeability and productivity of volcanic rocks. Highly productive volcanic rock aquifer systems are found in the Prescott AMA and in the Big Chino sub-basin of the Verde River basin. Statewide, water-bearing volcanic rocks are often found interbedded with basin-fill deposits in many groundwater basins. Volcanic rocks may also form local perched aquifers in various parts of the Colorado Plateau.

Groundwater is produced from fractured or decomposed crystalline bedrock in various local areas throughout the state. Probably one of the most well known examples of this type of aquifer is found in the Payson area where water is produced, in part, from fractured and/or decomposed granite formations (Parker, 2004). The bedrock aquifer system in the Payson area has been shown to yield appreciable amounts of groundwater for an extended period of time, and may have locally higher groundwater recharge rates than other similar areas of Arizona (Walker and Ploughe, 2008). In Payson, local officials hope to manage the groundwater resource to a safe-yield condition by limiting groundwater use to estimated recharge (Walker and Ploughe, 2008). While it is uncertain whether the Payson water management strategy will succeed over the next 100 years, the strategy does recognize the fact that extended groundwater production in any aquifer system that is in excess of recharge will eventually deplete the groundwater resource.

In general, low-yield volcanic and crystalline bedrock aquifer systems are not considered to be reliable aquifers because of their typically limited vertical and lateral extent and degree of saturation, low permeability, low storage capacity and limited recharge potential. For the purposes of this study, no attempt has been made to quantify depth-to-water relationships for these types of aquifers on a statewide basis. However, for the examples mentioned, the depth-to-water generally does not approach 1,200 feet BLS.

Groundwater Basins Adjacent to the Colorado River

Because the waters of the Colorado River are under the control of the Secretary of the Interior, ADWR recommends that the evaluation of physical availability of groundwater for water adequacy in groundwater basins that are adjacent to the Colorado River must take into account any potential diversions of federally controlled Colorado River water from wells. The 1,200 foot BLS depth-to-water criteria for water adequacy would also apply in any area of such groundwater basins, regardless of potential groundwater-surface water interactions.

Fundamental Components of Hydrologic Studies to Demonstrate Physical Availability

In order for a water supplier or developer to demonstrate that an adequate, 100-year water supply is physically available for a new subdivision, a hydrologic study of the area where the water supply is to be developed must be conducted. Although each study area is different, there are certain fundamental components to hydrologic studies that must be developed. Hydrologic studies should include:

- Groundwater exploration to identify areas where potentially productive and sustainable water supplies may be developed. Such studies provide data and information to help characterize the aquifer. In areas such as the Coconino Plateau groundwater exploration should be conducted using surface geophysical methods, geologic mapping and geophysical well logging.

- Long-term aquifer testing to develop aquifer parameters, hydrologic boundary conditions and well yield data (potentially for several weeks in duration in unexplored and unproven areas).

- Regional water level analysis to develop historic, as well as on-going, decline rate data and current depth-to-water information.

- Water quality sampling

- Analysis of existing and approved groundwater demands in the area

- Appropriate groundwater modeling (100-year predictive analysis)

- Long-term groundwater level monitoring (in areas where physical availability cannot be initially demonstrated).

A detailed description of the specific requirements for hydrologic studies is provided in ADWR's substantive policy statement on hydrologic studies demonstrating physical availability of groundwater for assured and adequate water supply applications (ADWR,2007A). However, the following section presents information on studies that are particularly relevant to areas where the physical availability requirements for demonstrating water adequacy may be modified.

<u>Groundwater Exploration</u>

The high cost of drilling deep wells in areas of limited groundwater resources makes it a necessity to conduct systematic groundwater exploration in advance of well site selection and drilling. In the Flagstaff area, the USGS and the City of Flagstaff partnered in an extensive groundwater exploration program to better understand the hydrogeology of the regional aquifer system (Bills, and others, 2000).

In that study the USGS conducted several types of remote-sensing techniques combined with geologic mapping. Data were collected from a variety of surface-geophysical techniques that included ground-penetrating radar, seismic reflection and refraction and square-array resistivity (Bills, and others, 2000). Gravity data were also used to identify major structural features and trends. The remote sensing and geologic mapping indicated that there were many significant surface structural features that include folds, faults, grabens, joints and other fractures that were not previously seen (Bills, and others, 2000). These features were shown to have a significant effect on the occurrence and flow of groundwater in the regional aquifer.

Another surface-geophysical method that has been shown to be useful in providing information on the location and depth of potentially water-bearing structures is the Controlled-Source Audio Frequency Magneto-Telluric (CSAMT) resistivity method. It has been reported that productive wells have been drilled in the Red Gap Ranch, Flagstaff and Bellemont areas at sites that are located along geologic structures identified by CSAMT surveys (Small, 2008). Time-domain electromagnetic (TEM) geophysical surveys are also used in groundwater exploration to locate fractures and faults (Zonge, 2008).

Faced with the difficulty of developing water supplies from the 3,000 foot deep R aquifer system, the City of Williams joined forces with the USGS in conducting an extensive geophysical exploration program to develop potential exploration targets in the Williams area (Pierce, 2001). The exploration methods used in the Williams study included gravity measurements, aeromagnetic measurements, audiomagnetotelluric (AMT) soundings, square-array resistivity (SAR), Thematic mapper, aerial photography, digital elevation model data and well data (Pierce, 2001). The results of the Williams groundwater exploration efforts were later shown to be successful in identifying at least one deep well site that was later drilled and shown to be moderately productive (City of Williams, 2007).

<u>Geophysical Well Logging</u>

Geophysical well logging is an activity that is used to evaluate the physical properties of the rock units penetrated by a well. Typical logging suites may be composed of caliper, gamma ray, e-log (short and long normal, lateral, spontaneous potential) and acoustic logs. Additional logging services that may be run include induction-electric, neutron, density, dip-meter, acoustic televiewer, video log, spinner, flowmeter, temperature log, etc. Running comprehensive geophysical logging suites in combination with lithologic logging is a very powerful combination that can produce excellent results for evaluating the subsurface. In the USGS-City of Flagstaff study the orientation of fractures and the production capacity of specific depth zones were identified in wells tested using some of these techniques (Bills, and others, 2000). Reports from hydrologists with the Town of Payson indicate that video logs and sonic logs are very helpful in identifying potentially productive saturated fractures (Walker and Ploughe, 2008). Geophysical well logging was proven to be an invaluable tool in one case of deep well exploration near Strawberry, Arizona, where loss of drill cuttings due to “lost circulation” conditions made it absolutely necessary to run geophysical logs to determine the lithologic units that were penetrated by the well below a depth of about 900 feet (Corkhill, 2000).

Aquifer Testing

Accurate, site-specific information about aquifer transmissivity, storativity, boundary conditions and well yield is a fundamental component of any hydrogeologic study. In most rural areas of the state, the aquifer systems are largely unexplored and untested and aquifer testing is essential. In general, the number of aquifer tests to be performed must be commensurate with the size of the project, the proposed volume of groundwater to be withdrawn, and the complexity of the hydrogeology of the aquifer system (ADWR, 2007A).

Although there may be general agreement that aquifer testing is required for a given area or proposed new development, there is almost always some debate concerning the specific requirements for the testing (both drawdown and recovery). Questions commonly arise concerning whether it is necessary to drill observation wells, how many tests may be required, how long the test should last, what pumping rate is acceptable, etc. The use of observation wells is advised whenever possible and in most situations the use of multiple observation wells will significantly enhance the knowledge gained from an aquifer test. Likewise, observations of water level recovery are very important, and should be routinely conducted as a part of any constant discharge aquifer test.

Questions related to determining what is an acceptable pumping rate and duration of aquifer testing are serious concerns for every aquifer test. However, when the results of the testing are used to support 100-year demonstrations of water adequacy these considerations become critical. The determination of an acceptable pumping rate for a constant discharge aquifer test should be based on the results of running a variable step-discharge test to determine the optimal operational pumping rate for the well. If the results of the step-test indicate that the well should be operated at a lower discharge rate than originally anticipated or desired, the developer will know that he may need to drill and test more wells to supply the desired volume of water (if the aquifer is actually capable of producing that volume). Although the pumping rate for the constant-discharge aquifer test should be commensurate with the long-term operational production rate of the well, the test pumping rate should also be sufficient to reasonably stress the aquifer and cause water level drawdown that can be accurately measured and distinguished from the effects of outside influences, such as barometric or diurnal fluctuations, regional water level trends, nearby pumping wells, etc.

The combination of pumping rate and duration of pumping ultimately determine the portion of aquifer that is evaluated during the aquifer test. In areas where substantial regional and local knowledge of the aquifer system already exists, a minimum 48-hour aquifer test is generally required to develop site-specific aquifer parameters. However, in areas of complex geologic structure where aquifer properties and characteristics are generally unknown, the length of aquifer testing should be considerably longer. In many instances, local water providers conduct long-term aquifer testing for their new and existing production wells. For example, the City of Flagstaff has reportedly conducted several long-term aquifer tests lasting from 52 days to as long as 225 days in duration (Montgomery and DeWitt, 1983). The City of Flagstaff has recently completed a 4 to 5 day aquifer test on a new high-capacity production well (test rate >1,300 gpm) that is located southwest of the city (Small, 2008). The Town of Payson reports that it requires developers of new subdivisions to conduct aquifer tests that may range from 3 days to 7 days in duration (Walker and Ploughe, 2008).

The Flagstaff and Payson examples clearly show an awareness of the need to conduct long-term pumping tests to develop information on local aquifer characteristics and operational limits of wells. However, the fundamental question still remains, "What duration of testing is really required to provide sufficient data to be confident in predictions that may be made based on the well test data concerning the 100-year drawdown of a well?". Previous analytical equations have been developed to quantify appropriate aquifer test duration in regards to observed drawdowns and identification of potential hydrologic boundary effects.

For example, Walton (1987) presented the following equation to determine the duration of a pumping test in an aquifer where a boundary was known to exist that would likely impact the results of pumping test:

$$t_{i\,=\,5.4\,X\,10^3}\,(r_i^2)S_{aw}/T$$

Where t_i = pumping test duration which must be exceeded if boundary impacts are to be clear (one time logarithmic cycle impacts become appreciable), in minutes

r_i = distance from observation well to boundary image well, in feet

S_{aw} = aquifer artesian or water table storativity, dimensionless

T = aquifer transmissivity , gpd/ft

It should be noted that, the equation presented by Walton (1987) requires or assumes prior knowledge concerning the existence and distance to boundaries. Unfortunately, this information is often unavailable or poorly known in structurally complex and heterogeneous aquifer systems. The complex aquifer systems of central and northern Arizona do not have a universally applicable rule of thumb that can be used to determine how long an aquifer test should be run to provide adequate information on the long-term (100-year) productivity of a well. In areas of complex hydrogeology where aquifer permeability is highly variable and fractures, faults and solution cavities serve as conduits or barriers to groundwater flow, it is possible that long-term testing may not provide the confidence level that is desired in making such long-term predications. However, the data collected from this long-term testing, even if inconclusive, will still prove valuable in analyzing the general hydrology of the project area.

Although there are no hard and fast rules of thumb concerning the appropriate duration of aquifer testing that may be required in areas of complex hydrogeology it is possible to examine this question using some examples that demonstrate how the portion of an aquifer that produces water during an aquifer test varies as the duration of the test increases. The portion of an aquifer that produces water during an aquifer test is defined by the well's "radius of influence". The "radius of influence" of a well is distance from the well where withdrawal of water from the well causes an insignificant decline in the piezometric (potentiometric) surface or water table (Bouwer, 1978).

Figure 6 shows the radius of influence of a well that has been pumped continuously at a rate of 250 GPM during a 2-day aquifer test. For the purposes of this example the assumed aquifer properties are transmissivity = 5,000 gpd/ft and storativity = .1. For computational purposes it was assumed that the radius of influence of a well could be approximated as being equal to the radial distance from a well where the calculated drawdown was equal to .1 foot of drawdown (at a specified time after pumping began). It should be noted that although there would actually be some decline of water levels beyond the approximated radius of influence, it was found that this method generally provided acceptable approximations of the theoretical radius of influence for most of the examples that are presented in this analysis. Figure 6 illustrates that after two days of pumping, the radius of influence of the well would be about 386 feet. The figure shows that minimal drawdown and groundwater storage change occurs beyond the approximated radius of influence. The significance of this fact is that the area of the aquifer that is located outside the radius of influence is essentially untested during the aquifer test. In this example, there would be no information gained about the nature of the aquifer beyond a distance of about 400 feet.

The radius of influence of a well grows as the duration of pumping increases. This relationship is shown in Figure 7. Figure 7 shows how the cone of depression and radius of influence of a well expands outward as the duration of pumping increases. In the example shown, the radius of influence grows from 386 to 721 feet with five additional days of pumping. From a practical standpoint, the additional five days of pumping has appreciably increased the portion of the aquifer that has been impacted and evaluated during the aquifer test.

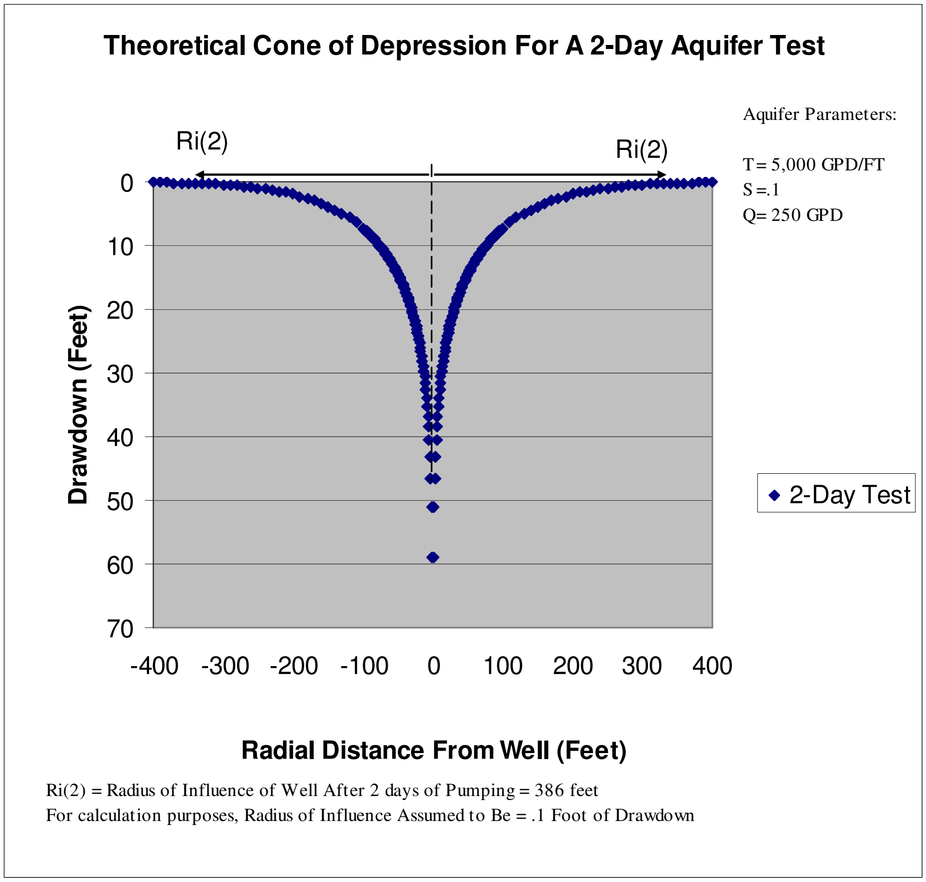

Figure 6 Theoretical Cone of Depression for a 2-Day Aquifer Test

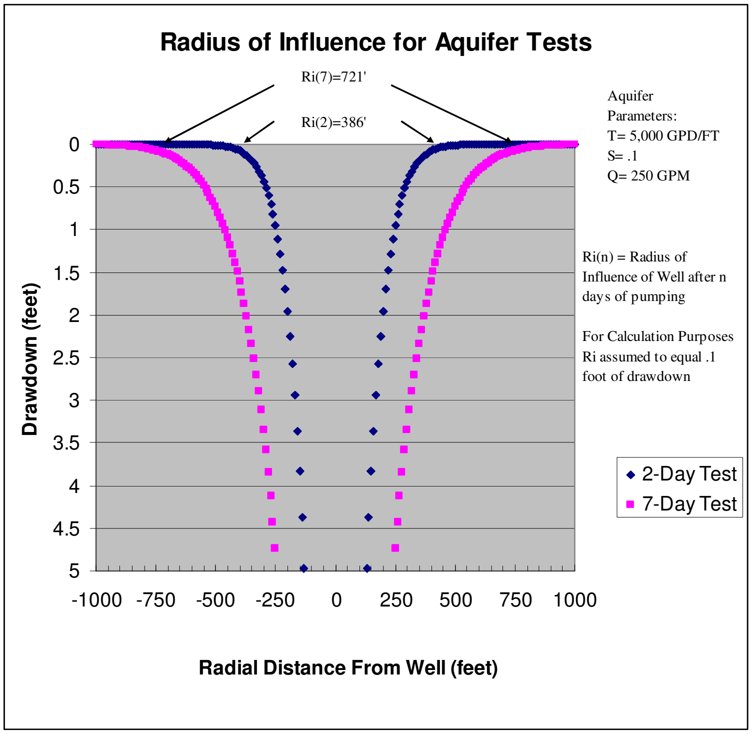

Figure 7 Radius of Influence for Theoretical Aquifer Tests

It has been shown that the duration of pumping plays an important role in determining the extent of the aquifer that is actually tested during an aquifer test. To examine this relationship more fully, a series of theoretical simulations was conducted to calculate the radius of influence of a well for periods of 1, 2, 7, 14, 30, 60, 90, 182, 365, 1825, 3650, 9125, 18,250 and 36,500 days (1 day to 100 years). The simulations were also conducted for a broad range of aquifer properties and pumping rates (see attached text file Appendix A). Results for the aquifer shown in previous examples are listed in Table 9.

The information presented in Table 9 shows how the radius of influence of a well increases as the duration of pumping increases. For the aquifer system analyzed (which would be considered a reasonable groundwater exploration target in many parts of rural Arizona) the data show that the radius of influence for a 90-day pump test would be about 2,500 feet (Table 9). The data show that the radius of influence would increase to over 52,000 feet in 100 years of continuous pumping at 250 gpm. The 20-fold increase in the radius of influence gives a clear indication that an aquifer test of 90 days would really only test a small portion of the aquifer that would be relied on to produce groundwater over a 100 year period. This point is made even clearer when it is realized that the volume of groundwater that would be produced over 100 years within a distance of 2,500 feet from a well would be about 1,500 AF (Table 9, column 9) which would be less than 4 percent of the 40,300 AF of groundwater that would be produced by the well over 100 years.

While it is true that we gain knowledge about the nature of the aquifer system within the area defined by radius of influence of a well, the fact is that many important features can escape detection if the length of aquifer testing is insufficient. To illustrate this situation an example has been prepared which shows how the results of an aquifer test would vary based on differing nearby boundary conditions (Figure 8).

The examples presented show the theoretical drawdown that would be observed at the location of a pumping well that penetrates an aquifer with: 1) no boundaries, 2) one north-south oriented boundary that is located 150 feet to the east of the pumping well and 3) two parallel north-south oriented boundaries, with one boundary located 150 feet east of the pumping well and the other boundary located 150 feet to the west of the pumping well. It should be noted that this example was developed based on geologic relationships that may be common in many parts of the Coconino Plateau.

For example, in the Bellemont area, water production rates of deep wells are highly dependent upon whether a well penetrates a productive zone in the Bellemont fault system that runs through the area (Wilkinson, and Nation, 2007) (Hydrosystems, 2007). Studies of exposures of normal faults in canyons at the edge of the Coconino Plateau indicate that the fault plane of a normal fault cutting through the Coconino Sandstone can have a damage zone of up to 60 meters wide (Kelly, 2000). The term “damage zone” refers to zones of intense fracturing, faulting and brecciation along the fault plane (Kelly, 2000). Where saturated, such damage zones undoubtedly form preferential flow paths in the regional aquifer system.

Table 9 Data on the radius of influence of a well for various length aquifer tests

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time (t)	DD at r=1'	Ri(t)	Ri (36500)	Col 3/ Col 4	VolRi(t)	VolRi (36500)	Col 6/ Col 7	VolRi(t) At 36500	VolRi (36500)	Col 9/ Col 10	Totq(t)	Totq (36500)	Col 12/ Col 13
Days	Feet	Feet	Feet		AF	AF		AF	AF		AF	AF	
1	55	273	52,054	.005	1.09	39,776	.0000	30.5	39,776	.0008	1.1	40,328	.0000
2	59	386	52,054	.007	2.18	39,776	.0001	56.7	39,776	.0014	2.2	40,328	.0001
7	66	721	52,054	.014	7.63	39,776	.0002	171.0	39,776	.0043	7.7	40,328	.0002
14	70	1,020	52,054	.020	15.26	39,776	.0004	312.4	39,776	.0079	15.5	40,328	.0004
30	75	1,493	52,054	.029	32.69	39,776	.0008	599.2	39,776	.0151	33.1	40,328	.0008
60	79	2,111	52,054	.041	65.39	39,776	.0016	1,070.6	39,776	.0269	66.3	40,328	.0016
90	81	2,585	52,054	.050	98.08	39,776	.0025	1,493.9	39,776	.0376	99.4	40,328	.0025
182	85	3,676	52,054	.071	198.34	39,776	.0050	2,269.7	39,776	.0661	201.1	40,328	.0050
365	90	5,206	52,054	.100	397.76	39,776	.0100	4,502.6	39,776	.1132	403.3	40,328	.0100
1825	98	11,640	52,054	.224	1,988.80	39,776	.0500	13,801.7	39,776	.3470	2,016.4	40,328	.0500
3650	102	16,461	52,054	.316	3,977.58	39,776	.1000	20,567.3	39,776	.5171	4,032.8	40,328	.1000
9125	107	26,027	52,054	.500	9,943.94	39,776	.2500	30,763.7	39,776	.7734	10,082.0	40,328	.2500
18250	111	36,808	52,054	.707	19,877.9	39,776	.5000	36,894.0	39,776	.9275	20,164.0	40,328	.5000
36500	115	52,054	52,054	1	39,776	39,776	1.0000	39,776	39,776	1.0000	40,328	40,328	1.000

Assumed Aquifer Parameters and Related Data:

Radius of Influence Ri(t) is approximated as = .1 foot of drawdown at the time specified by (t)

Transmissivity = 5,000 gpd/ft

Storativity = .10

Pumping rate = 250 gpm

Total volume of groundwater produced from within the radius of influence after 100 years = VolRi(36500) = 39,776 AF

Total volume of groundwater pumped after 100 years = Totq(36500) = 40,328 AF

VolRi(36500)/Totq(36500) = .986

t = time in days of pumping

DD at r=1' = drawdown at radius =1 foot at the time indicated (essentially indicates drawdown at well)

Ri(t) = radius of influence of well at the time indicated

Ri(36500) = radius of influence of well at 36500 day (100 years)

VolRi(t) = volume of groundwater produced from within radius of influence at the time indicated

VolRi(36500) = volume of groundwater produced from within radius of influence at t=36500 (100 years)

VolRi(t) at 36500 = volume of groundwater produced after 100 years from within radius of influence at the time indicated

Totq(t) = total volume of groundwater pumped at the time indicated

Totq(36500) = total volume of groundwater pumped at t=36500 (100 years)

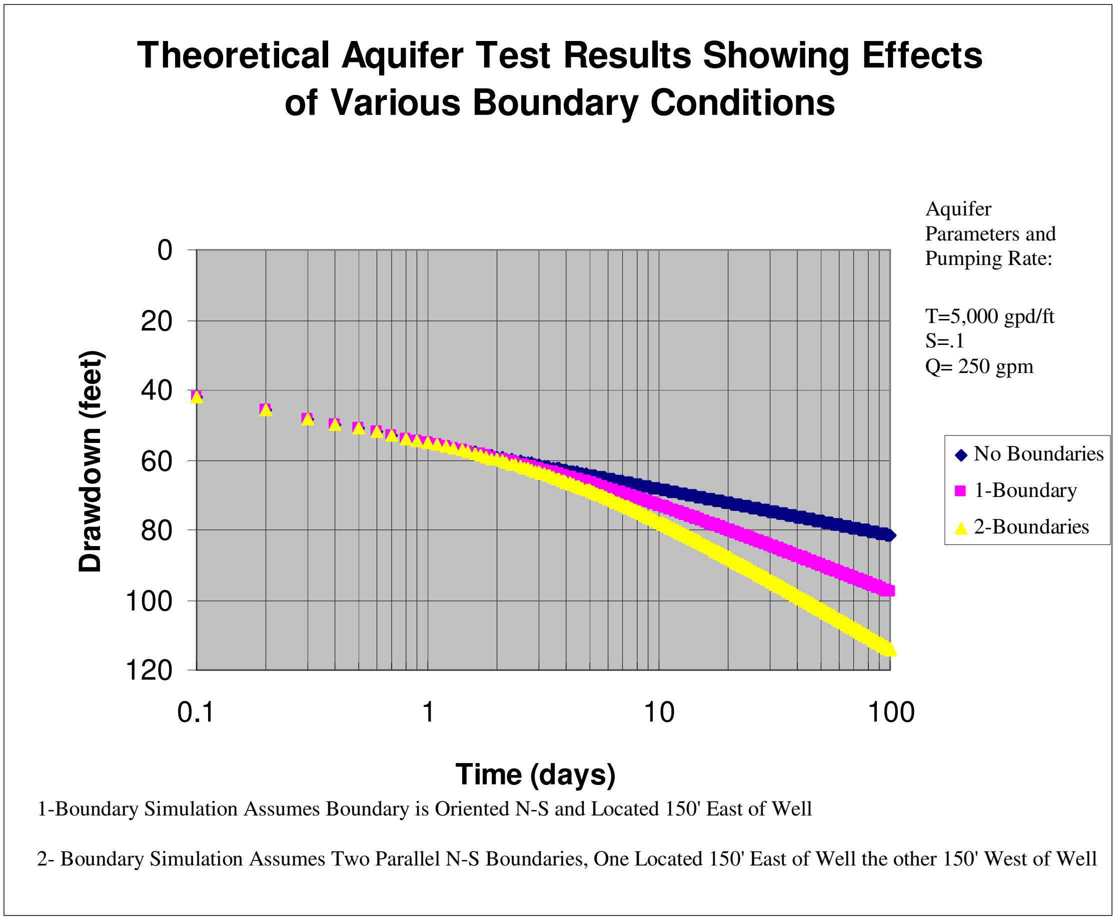

Figure 8 Theoretical Aquifer test results Showing Effects of Various Boundary Conditions

Figure 8 shows that an aquifer test of 5 to 7 days would probably be sufficient to develop representative data on aquifer transmissivity if no aquifer boundaries or heterogeneities existed (as indicated by the straight-line response of the "no-boundary" response curve). However, the examples show that a 5 to 7 day test would probably not identify the existence of nearby boundaries (as indicated by the gradual slope of the "1 and 2 boundary" response curves after about 5 to 7 days of pumping). Indeed, the boundary impacts may be over-looked or discounted unless far longer testing was conducted to confirm the trends. While missing these boundaries may seem unlikely to a trained hydrogeologist, such oversights can occur, and the consequences can be drastic if predictions that a long-term water supply was available were made based upon the mis-interpretation of existing boundaries.

At this point it is reasonable to question whether aquifer testing can, in itself, provide the necessary level of certainty to reasonably determine whether a 100-year water supply is physically available. The answer to this question depends upon the physical characteristics of the aquifer system and the degree to which the aquifer system has been previously explored and produced. In many of the alluvial aquifer systems of central and southern Arizona there is a long history of groundwater exploration and water production. In such areas thousands of wells have been drilled and the general extent, depth and water producing characteristics of the aquifer systems are comparatively well known, and a greater level of confidence in long-term production predictions is justified. However, even in these comparatively well characterized areas, that often have more "uniform" aquifer characteristics than the complex consolidated sedimentary rock aquifers of northern Arizona, the level of certainty in long-term predictions about water supplies diminishes as groundwater development spreads to previously unexplored areas. In most parts of northern and central Arizona the aquifer systems are comparatively complex and unexplored and reliance on limited aquifer testing, that is unsupported by other data, to predict long-term physical availability of groundwater often may exceed reasonable limits.

It is also important to mention that analyzing the results of aquifer test data from complex heterogeneous aquifer systems may require special techniques that go beyond the standard Theis (1935) or Cooper-Jacob (1946) methods. For example, the fractured and decomposed granitic aquifer in the Payson area shows a clear "delayed-yield" response that should be accounted for in the analysis of aquifer test data (Walker and Ploughe, 2008). In the Flagstaff area the results of a 7-day aquifer test at a municipal well in the Lake Mary well field could not be analyzed using standard techniques because of complex boundary conditions, and a numerical groundwater model was developed to simulate the results of aquifer testing (Kelly, 2000).

<u>Regional Water Level Analysis</u>

Analysis of regional water level trends is an important part of hydrologic studies. Regional water level declines caused by natural conditions or anthropogenic activities such as groundwater pumping must be accounted for in the analysis of long-term physical availability. Water level data provide current information used to determine the initial depth-to-water for physical availability analyses. Long-term water level decline rates are also used to evaluate 100-year physical availability. Regional water level decline rate data may be used directly in combination with predictions of future groundwater declines provided by analytical models to evaluate 100-year physical availability. Calibrated numerical models rely on long-term water level data to guide model calibration. Unfortunately, in many areas of the state, long-term water level data are limited or completely unavailable and conservative assumptions are therefore used.

<u>Water Quality Sampling</u>

Water quality sampling should be conducted with any hydrologic study. Water quality data not only provide general information on the suitability of the water supply for human consumption, but can also potentially provide important data on source areas of aquifers, groundwater flow paths, groundwater residence times, etc. In areas that have poor quality water, depth-specific sampling of wells can provide valuable information that can allow hydrologists to determine if portions of the aquifer that contain contaminants can be effectively sealed off from the well. While the Arizona Department of Environmental

Quality maintains the responsibility of regulating the quality of water provided by municipal water systems, there are no such regulations for domestic wells drilled to supply dry lot sub-divisions. Information on groundwater quality is required by ADWR to determine if appropriate water quality standards are met.

While water quality has not been traditionally considered to be a direct component of the physical availability analysis, the cost of treating poor quality water to drinking water standards may become a more important consideration, particularly as new development spreads into areas where water quality is marginal or sub-standard.

Analysis of Existing and Approved Demands

The analysis of current and committed demands is a fundamental component of all hydrologic studies that are used to evaluate physical availability. This analysis must include the impact on the current depth-to-static water level from all existing uses of groundwater within a study area, demands associated with recorded lots not yet being served, demands associated with all issued determinations of assured water supply and determinations of adequate water supply within a study area ("issued demands"), and the demand associated with the application itself ("application demand"). Also, per session law, maybe some future uses, such as mine pumpage. A detailed description of the specific requirements for this component of hydrologic studies is provided in ADWR's substantive policy statement on hydrologic studies demonstrating physical availability of groundwater for assured and adequate water supply applications (ADWR,2007A).

Groundwater Modeling (100-Year Predictive Analysis)

The prediction of the 100-year depth-to-water is the fundamental test of the physical availability analysis. The analysis is designed to account for the future impacts of a proposed new development, in addition to future impacts of all existing and approved uses and regional water level decline trends. A detailed description of hydrologic modeling techniques is provided in ADWR's substantive policy statement on hydrologic studies demonstrating physical availability of groundwater for assured and adequate water supply applications (ADWR,2007A). However, the following discussion is focused on special modeling techniques that may be required to simulate groundwater flow in the complex heterogeneous aquifer systems.

A conceptual model of a physical availability analysis is shown in Figure 9. In the example shown, the current depth-to-water is shown to be 200 feet BLS. The analysis contains a component of future water level decline that is based on observations of historic long-term water level data. Based on an estimated regional decline rate of 3 feet per year the depth-to-water in the aquifer would be estimated at 500 feet BLS after 100 years with no increase in demand. The analysis also includes 400 feet of additional projected water level decline at the wells serving the new development. This accounts for the new projected pumping of the development itself and also the approved uses in the area. Based on the example presented the projected 100-year depth-to-static water level at the wells serving the new development would be 900 feet BLS which would be above the 1,200 foot depth-to-static water level pumping criteria for demonstrating water availability.

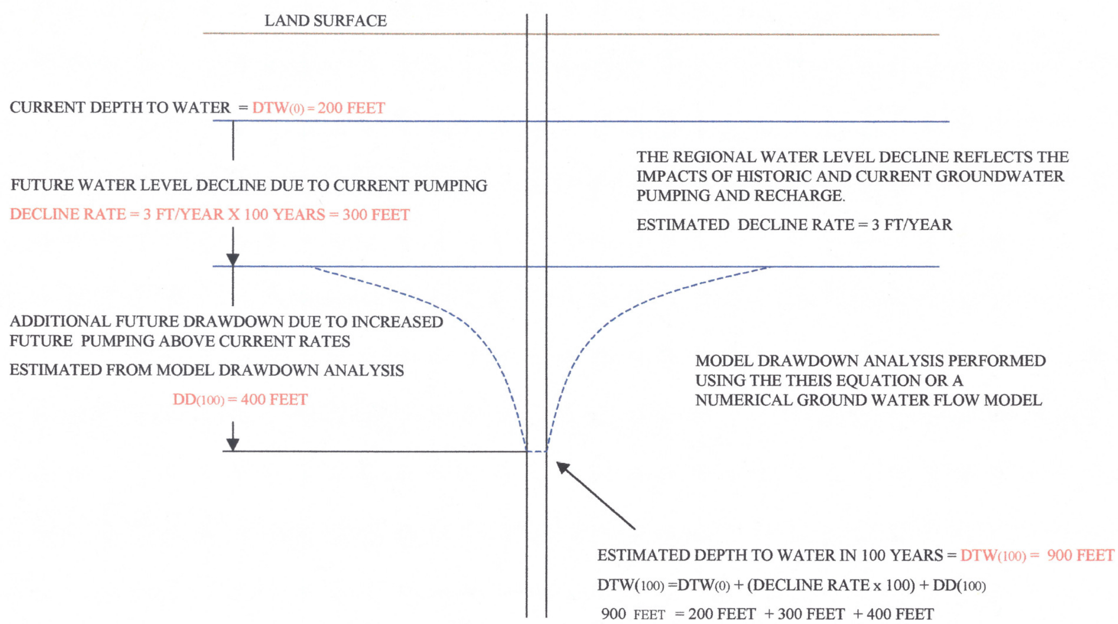

Figure 9 Conceptual Model Showing a Physical Availability Analysis Using an Analytical Model

In the example presented, the analysis of future drawdown was accomplished using an analytical model that solves the Theis (1935) equation. While analytical models have been widely used for many such analyses, the use of analytical models in areas of complex, heterogeneous hydrogeology is generally inappropriate. Factors that limit the use of the Theis equation in areas of complex geology often include: primary and secondary flow mechanisms, complex boundary conditions, anisotropy, heterogeneity, non-laminar flow, partial penetration of wells, etc. In such areas an aquifer may be more appropriately simulated using a model that can account for variations in aquifer properties and boundary conditions. Such models are generally referred to as numerical groundwater flow models (Figure 10).

Numerical groundwater flow models are probably the best tools that are currently available to analyze complex aquifer systems. Flow through primary and secondary porosity features have been handled in a variety of ways using numerical models. In some areas groundwater flow through primary and secondary porosity features has been combined into an equivalent porous medium (EPM) model. This approach has been shown to be appropriate, at least at a regional scale. For example, the ADWR Prescott AMA model effectively simulated complex flow through volcanic units in the Little Chino sub-basin using an EPM approach (Corkhill and Mason, 1995).

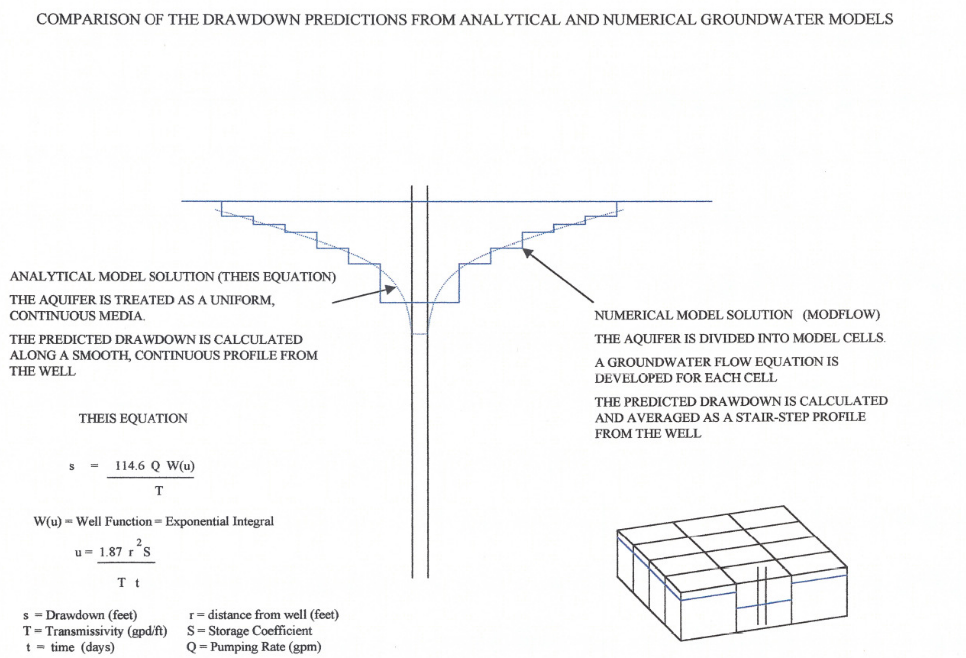

Figure 10 Comparison of Drawdown Predictions From Analytical and Numerical Groundwater Models

Although the equivalent porous medium approach may be acceptable for some regional areas, the approach is hardly justified on a local or sub-regional scale in a highly anisotropic fractured rock aquifer or karst aquifer (Kresic, 2007). Features such as complex boundaries, faults, fractures or major solution cavities may be directly simulated using a numerical groundwater flow model (depending on model cell-size). Additional model options such as the Horizontal Barrier Package (Hsieh and Freckleton, 1993) that are available with the USGS MODFLOW groundwater flow model (USGS, 1988) make it possible to place internal barriers representing local aquifer boundaries that may be caused by faults or other structural features within a model. Special grid options are also available with MODFLOW that make it possible to refine the model grid in areas where small-scale structural features may exist.

It is important to mention that even though modeling tools may be available to simulate complex aquifer features, the fact is that such models often fail to provide accurate predictions of future conditions. In some cases it is possible that substantial turbulent flow occurs in the aquifer system through fractures, faults or solution cavities. In such cases, a numerical model that is based on an assumption of laminar flow (Darcy flow) would be inappropriate. However, in many cases, the most likely short coming of models developed for fractured rock aquifers is that the aquifers are far more complex than the models constructed to simulate them. In general, such models can be improved with additional hydrogeologic data collection and analysis to create an average of the aquifer properties and behavior. However, there is no guarantee that any reasonable amount of additional data collection or analysis can provide high-confidence predictions, particularly for a 100-year time period.

Long-term groundwater monitoring

Long-term groundwater monitoring should be a part of any hydrologic study. Historically such monitoring has not been required as a condition to obtain or maintain an adequate water supply status. However, due to the significant uncertainties mentioned in determining if an adequate water supply is physically available in some parts of the state where complex hydrogeology reduces the confidence in any long-term water production predictions, it seems reasonable to require long-term monitoring. In such situations the volume of groundwater that would initially be approved for water adequacy purposes would be less that the volume that has been shown to be theoretically available under the ADWR physical availability criteria.

Using a gradual, phased-in approach to subdivision development where more groundwater may be approved in the future if long-term monitoring indicates it is appropriate to do so, would provide the necessary time to monitor the aquifer production over an extended period and thereby reduce the chances of a gross over-estimation of aquifer capacity.

Cost Considerations

Costs to explore for groundwater, drill and log wells, install casing and pump equipment and produce groundwater water are important factors to consider when evaluating whether a developer or water supplier has the financial capability to provide an adequate water supply. The following examples are presented only to provide a general sense of the costs associated with the various activities. Actual costs for drilling a well are highly dependent upon site-specific conditions and total well depth.

Costs (based on 2008 pricing) for geophysical exploration such as the use of CSAMT or TEM surveys in hardrock aquifer areas can be highly variable in price. The costs for running a few CSAMT lines in an area where geologic structure is at least somewhat known, and can help focus the extent of the surveys, may run in the $20,000 to $30,000 range (Urquhart, 2008). However, in other areas where substantial data collection and analysis is required the cost of surveys can exceed several hundred thousand dollars (Urquhart, 2008).

Costs for running three recent CSAMT surveys that identified 8 potential new well sites for the City of Flagstaff ran about $40,000 per survey (Small, 2008). Based on experience in northern Arizona, the cost to run CSAMT surveys may run about $2.25 to $2.50 per foot (Small, 2008).

Costs to drill domestic wells in the Payson area are estimated to be about $25,000 to $30,000 (Small, 2008). USGS personnel estimate the costs of drilling domestic wells in the Mohave county area may be about $25,000 (Leenhouts, 2008).

Costs for drilling high capacity municipal wells in the alluvial basins of central Arizona may run in the $600,000 to $800,000 range (Small, 2008). However, well drilling costs in deep hardrock aquifers of northern Arizona are generally much higher. For example, costs for drilling four deep (>2,000 foot), 12-inch diameter, production wells for the City of Flagstaff are estimated have been about $1.2 million to $1.5 million (Small, 2008). Costs for running aquifer tests on these wells run in the range of $200,000 to $250,000 per well. The costs to run geophysical well logs on the new Flagstaff wells ran about $4,000 to $6,000 per well. Video logging cost for these wells ran in the $1,500 to $2,000 range (Small, 2008).

Costs to drill, case, develop and install pumping equipment in a 3,000 to 4,000 foot deep water production well that was drilled for the City of Williams into the Redwall Limestone along the Mesa Butte Fault zone are reported to have run in the $2 million to $3 million range (City of Williams, 2007). The reported costs to pump this well which has a depth- to-water that exceeds 3,000 feet BLS and other City of Williams wells at peak rates that produce a combined total volume of several hundred gallons per minute is in the $100,000 per month range (City of Williams, 2007).

The costs of drilling 700-foot deep production wells in the Showlow area that are capable of producing 300-500 gpm from the Coconino Sandstone run from about $250,000 to $350,000 per well (Small, 2008). In the Showlow area groundwater production rates from the Coconino Sandstone are not as dependent upon geologic structure, and the Coconino Sandstone seems to be generally more broken up and productive (Small, 2008).

In 2000 the Northern Gila County Water Plan Alliance drilled a deep exploration borehole (later converted to a monitor well) in the Strawberry area that penetrated a thick sequence of Paleozoic sedimentary rocks to a total depth of 1,872 feet (Corkhill, 2000). Drilling conditions were very difficult with considerable down time being encountered due to "lost-circulation" zones and other problems. The cost to drill, case and run geophysical well logs for the well was approximately $150,000.

In 2001 the ADWR acquired leases on 3 parcels of state land in the Prescott AMA to drill monitor wells. The Department hired a local drilling contractor to drill and complete the wells. The wells penetrated alluvial and volcanic formations and drilling conditions varied from easy to difficult. The costs of drilling, installing steel casing and gravel pack and geophysical logging the wells that had total depths of 840 feet, 654 feet, and 1,240 feet were $43,000, $34,500 and $60,000, respectively. The cost to run a standard set of geophysical logs on each well was about $3,000 per well.

Summary

The increasing awareness of the special problems and issues that confront water providers and other water users in rural Arizona in finding, developing and producing adequate water supplies resulted in the adoption of § 10(B) (2) of S.B. 1575, which requires the ADWR to amend its Assured Water Supply rules to establish criteria for demonstrating a physically available one hundred-year supply of groundwater or stored water in specific aquifer systems and groundwater basins and subbasins outside AMAs.

The information presented in this report shows that the depth-to-water currently approaches or exceeds the 100-year depth-to-static water level limit of 1,200 feet BLS over large portions of the structurally complex, regional aquifer system of central and northern Arizona. Depths-to-water also currently approach or exceed 1,200 feet BLS in portions of the alluvial basin-fill aquifer systems of northwestern Arizona. Well construction data indicate that about 75 percent of the registered domestic wells in the state have depths that are less than 400 feet BLS.

The evaluation of physical availability of groundwater for water adequacy in groundwater basins that are adjacent to the Colorado River must take into account any potential diversions of federally controlled Colorado River water.

Information on the requirements of hydrologic studies indicates the need for systematic groundwater exploration, long-term aquifer testing, the collection water quality and water level data, the compilation of groundwater demand data, appropriate groundwater modeling and long-term groundwater monitoring.

Costs to explore for groundwater, drill and log wells, install casing and pump equipment and produce groundwater are important factors for a developer or water supplier to consider when proving an adequate water supply in data limited areas located outside of AMAs.

Recommendations

- **No modification of the 1200-foot BLS 100-year depth to static water adequacy criteria for most areas of the state.**

  Based on the Department's review of current available data and information, the existing physical availability criterion of 1200 feet BLS for determinations of adequacy (analysis, water reports, designations, and PADs) is an appropriate maximum 100-year static water level depth limit for most areas of the state.

- **For the C and R aquifers the 100-year depth to static water adequacy criteria should be based on the remaining saturated thickness.**

  The Department recommends modification of the current 1200-foot BLS 100-year depth to static water level criteria in central and northern Arizona. This modification is recommended in either the C or the R regional aquifer systems. The criteria include:

  - The proposed groundwater withdrawals must be from wells that are planned to withdrawal groundwater from either the C or the R aquifer systems.

  - A hydrologic study must be conducted that demonstrates that at least 50 percent of the estimated original saturated thickness of the aquifer will remain after 100 years of withdrawing groundwater to meet all existing, approved, and project demands within the study area.

  - Projects that are projected to have less than 50 percent of the estimated original saturated thickness of the producing aquifer system remaining after 100 years of withdrawing groundwater to meet the demands of all existing, approved, and project demands within the study area will not be allowed.

  - Site-specific hydrologic studies that include geophysical exploration, well drilling and logging, aquifer testing, water quality sampling and appropriate groundwater modeling methods, such as the studies that were mentioned earlier in this report for the cities of Flagstaff and Williams, must be conducted to provide hydrogeological data and evidence that a 100-year water supply is available below a depth of 1200 feet BLS.

  - A pre-application between the applicant and ADWR must occur prior to conducting fieldwork and preparation of the hydrologic report.

- The total saturated thickness (at time of application) of the C or R aquifer in the location of the proposed project must be initially estimated from the following:

  - A current depth to static water level (in feet BLS) from a well on or within one mile of the proposed project area.

  - The bottom depth of the saturated aquifer unit, which may be estimated from:

    - Accurate hydrogeologic data and interpretations based on well log data from wells drilled within the study area.
    - Regional hydrogeologic data, such as published information on stratigraphic relationships and formation thicknesses
    - Site-specific geophysical surveys

Projects that are projected to have at least of 70 percent of the estimated original saturated thickness of the producing aquifer system remaining after 100 years of withdrawing groundwater to meet the demands of all existing, approved, and project demands within the study area, must provide a hydrologic study that contains the following data and information:

- Localized hydrogeological data including drilling and aquifer testing at a minimum of **one** water production well per square mile in the area where the proposed withdrawals from the aquifer system will occur. The minimum number of wells required will depend on the total area in which the production wells are to be located. For example, the hydrologic study area for a proposed new development might cover an area of a few hundred square miles and the property to be developed may cover an area of a dozen square miles. However, if all proposed production wells are to be located on the development property within an area of two square miles, then a minimum of two water productions wells would be required. The total depth of the wells must extend, at a minimum, to the projected 100-year depth to static water level of the proposed development.

- Aquifer testing must be conducted for each well for a minimum of **seven** days at the appropriate demand volume. However, as a general practice, longer duration aquifer testing is highly recommended.

- Other additional data may be used as support (but not as a replacement for localized data and aquifer testing) for physical availability in the study area such as:

  - Flow net analysis
  - Long-term records of pumping in the area
  - Other hydrogeologic evidence

- Appropriate impact analysis to determine the 100-year depth to static water level for estimation of the remaining saturated thickness under the proposed project (at the proposed production well locations). Analytical modeling techniques will not be allowed for modeling the R and C aquifer systems of northern Arizona except for projects that have annual groundwater demands of less than 100 acre-feet/year.

- If the data are not available and the applicant is unable to collect all of the needed data the follow options may be available:

    - Applicant may reduce the volume requested to a volume that can be substantiated by existing data
    - Applicant may propose phasing-in of demand volumes based on additional data collection. Phased development concepts are explained more fully below.

- A pre-application between the applicant and ADWR must occur prior to conducting fieldwork and preparation of the hydrologic report.

Projects that are projected to have less than 70 percent but at least 50 percent of the estimated original saturated thickness of the producing aquifer system remaining after 100 years of withdrawing groundwater to meet the demands of all existing, approved, and project demands within the study area, must provide a hydrologic study that contains the following data and information:

- Localized hydrogeological data including drilling and aquifer testing at a minimum of **one** water production well per square mile in the area where the proposed withdrawals from the aquifer system will occur. The total number of wells should be based on an assessment of the complexity of the aquifer system and on the total proposed water demand. The minimum number of wells required will depend on the total area in which the production wells are to be located. For example, if all proposed production wells are to be located within two square miles, then a minimum of two wells would be required. The total depth of the wells must extend, at a minimum, to the total depth of the producing aquifer.

- Aquifer testing must be conducted for each well for a minimum of **thirty** days at the appropriate demand volume. Aquifer testing can be conducted for as long as needed to collect the needed data. This duration must be based upon the proposed annual volume of the project and on an assessment of the structural complexity of the aquifer system. Prior to performing aquifer testing, the applicant should seek approval from ADWR as to the length and volume appropriate for the project.

- Geologic mapping and sub-surface characterization of aquifer structure and features using surface geophysical methods must be utilized to increase the reliability of the groundwater supply estimate.

- Appropriate impact analysis to determine the 100-year depth to static water level for estimation of the remaining saturated thickness under the proposed project (at the proposed production well locations). Analytical modeling techniques will not be allowed for modeling the R and C aquifer systems of northern Arizona. However, analytical modeling techniques may be appropriate for projects that have annual groundwater demands of less than 100 acre-feet/year.

- If the data are not available and the applicant is unable to collect all of the needed data a phasing-in of demand volumes based on data collection may be an option.

- A pre-application between the applicant and ADWR must occur prior to conducting fieldwork and preparation of the hydrologic report.

- **Phased development based on long-term groundwater monitoring for the C and R aquifers**

In some areas in northern Arizona, it may not be possible to initially demonstrate that an adequate 100-year water supply exits for a proposed new subdivision. Even if regional hydrogeologic data suggests the possibility that a 100-year groundwater supply does exist, localized data still must be used to prove the percentage of the saturated thickness of the aquifer that would remain after withdrawing groundwater to meet the demands of all existing, approved, and project demands within the study area. The number of wells that must be drilled and tested must be based on the projected size, demand, and complexity of the aquifer system which may make it necessary to initially drill several exploration and production wells before the time that the wells would actually be needed to produce water for the development. In some cases this may not be an option for a developer or water provider due to economics, timing of the development, or other restraints. A pre-application meeting between the applicant and ADWR must occur prior to conducting fieldwork and preparation of the hydrologic report.

In situations such as these, it may be appropriate for an applicant to seek a phased determination that would allow the groundwater supply to be demonstrated over an extended period of time. Because the appropriate number of wells and testing may not initially be available to prove the full demand volume, the full volume for the entire project cannot be allocated. For example, based on a combination of limited site-specific groundwater exploration data, well drilling, aquifer test data, and regional hydrogeologic data it may be appropriate to issue a phased determination that would allow an applicant to obtain an initial volume of groundwater for the first stage of development and subsequent volumes of groundwater in phased increments.

Using a phased approach for proving groundwater supply makes it possible to monitor the aquifer response as development occurs. Limited site-specific data can be interpreted, to include a minimum (dependent upon the size and demand of the proposed project) of geophysical surveys to identify potential production well sites, one drilled production well, and one drilled monitor well. An estimate of the saturated thickness must also be prepared using all available data. An appropriate impact analysis must also be performed to demonstrate physical availability for all phases of the determination. It is proposed that the phases be in appropriate length increments (based upon the developments general plan and need for additional phased groundwater supplies) unless the applicant can reasonably demonstrate that the hydrologic exploration and associated data collection will be accelerated. All work to be performed in the phases must be reviewed and approved by the Department prior to implementation.

In order to obtain a phased determination in the C and R aquifer systems of northern Arizona, the applicant must agree to conduct long-term groundwater monitoring using dedicated monitoring well(s). These wells will provide information on the actual response of the aquifer system to long-term pumping stresses. After the initial phase and associated proven groundwater supply, it may be possible for an applicant to obtain a second allocation of groundwater if all monitoring and testing can accurately prove an additional volume of water. There is no time limit between phases. The time required depends on how long it takes the applicant to collect the needed data to prove additional groundwater supplies exist to meet all demands in the area of the development for the next phase. The long-term monitoring must indicate that the aquifer response is generally as predicted and that all well drilling results and testing are favorable to prove the additional requested volume. This phased approach could be continued for as many phases as required to meet the build-out volume as long as the appropriate monitoring and additional drilling and testing continues. If the groundwater supply in the area of the development experiences negative conditions such as accelerated groundwater declines or decreased well yields, no further phased groundwater allocations would be allowed.

- **No modification of the 1200-foot BLS 100-year depth to static water adequacy criteria for basin-fill aquifers of northwestern Arizona.**

In reviewing the available data it was noted that the depth-to-water currently approaches or exceeds 1,200 feet BLS in some of the basin-fill aquifers of northwestern Arizona. In looking at this situation it might be asked why the Department does not recommend modification of the 1,200 foot water adequacy limit for that area as well. The reason that ADWR is not recommending modification of the 1,200 foot depth criteria for the northwestern basin-fill aquifer systems is because the existing and approved future water demand for those basins already represents a significant volume of groundwater that, when pumped, will lower the depth-to-water throughout those basins to a depth of or exceeding 1,200 feet BLS within 100 years.

It could be argued that the situation in the northwestern basin-fill aquifer systems is no different than the situation in the R and C aquifer systems, however there is a significant difference between the overall volume of groundwater that is stored within the northwestern basin-fill aquifers and the volume of groundwater stored within the R and C aquifer systems. For example, the estimated volume of groundwater in storage in the C aquifer in the Little Colorado River Plateau and Coconino Plateau basins exceeds 400,000,000 acre-feet (ADWR, 2006 and 2007B), while the estimated combined volume of groundwater in storage in the Detrital, Hualapai and Sacramento basins (to depth of 1,200 feet BLS) ranges from 15 to 18.5 million acre-feet (Mason and others, 2007), (Conway and others, 2007) and (ADWR, 2007C). When the existing and approved groundwater demands for each area are compared to their estimated storage volumes the northwestern basin-fill aquifers are found to have far less remaining groundwater in storage compared to projected demand than the R and C aquifer systems.

Although ADWR does not recommend changing the current 1,200 foot depth criteria for the northwest basin-fill aquifer systems, it does recognize that there may be certain special situations where it would be appropriate to grant a variance to exceed the 1,200 foot limit. ADWR may consider variance requests in such situations on a case by case basis.

- **No modification of the 400-foot BLS 100-year depth to static water adequacy criterion for dry lot subdivisions anywhere in the state.**

ADWR does not recommend modification to the 400-foot depth to water criterion for dry lot subdivisions. It does not seem appropriate to modify the existing depth criteria because of the problems (water quality and cross-contamination, well interference, etc.) caused by drilling individual wells on each lot at depths where aquifer reliability is often less certain and the costs of drilling or deepening wells may become a significant percentage of the total cost of home development.

Although ADWR does not recommend changing the current 400-foot depth to water criterion for dry lot subdivisions, it does recognize that there are some areas where average domestic well depths currently exceed 400 feet. In such areas it may be appropriate to grant a variance to exceed the 400-foot limit, to a maximum allowable depth-to-water of 600 feet BLS. However, a variance to exceed the 400-foot BLS depth-to-water criteria for dry lot subdivisions may only be granted if sufficient well drilling and aquifer testing are conducted that demonstrate that an adequate water supply is available at each lot (which is also required for determining water adequacy at the 400-foot BLS depth criteria). Additionally, special well construction standards may be required that would require new wells to be properly constructed and grouted to prevent potential vertical cross-contamination.

- **Adoption of the criteria that evaluate groundwater surface water interactions for groundwater basins adjacent to the Colorado River.**

  Because the waters of the Colorado River are under the control of the Secretary of the Interior, ADWR recommends that the evaluation of physical availability of groundwater for water adequacy in groundwater basins that are adjacent to the Colorado River must take into account any potential diversions of federally controlled Colorado River water from wells. The 1,200 foot BLS depth-to-water criteria for water adequacy would also apply in any area of such groundwater basins, regardless of potential groundwater-surface water interactions.

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Many of the USGS publications listed are available as free pdf downloads or for a nominal fee at: water.usgs.gov or az.water.usgs.gov

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